On the Relation of Adult Sockeye Salmon (*Oncorhynchus nerka*) Returns to Known Smolt Seaward Migrations[1]

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ABSTRACT

Data were obtained from Cultus Lake giving (*a*) the number of seaward migrating smolts each year from 1927 to 1944, (*b*) their mean length and weight, and (*c*) the number of adults from each smolt migration which returned in the spawning escapement to the lake. These indicate a negative correlation ($-.5$; 24, $P < 0.05$) between number of smolts and percentage return of adults. By multiple regression this is shown to be related almost wholly to the size of the smolts. With an increase in average weight of smolts from 4 to 10 grams, their average percentage survival is tripled.

Smolt size and numbers together account for about 60 per cent of the variation in actual number of adult salmon which arrive at the lake. The residual variability could not be definitely related to available qualitative indices of fishing intensity or duration.

INTRODUCTION

In the management of Pacific salmon fisheries it has been the practice to endeavour to arrange—as the fish come into coastal areas from the sea—such a division between the commercial catch and the spawning escapement that the latter, representing the seeding, will be adequate to perpetuate the population at a reasonably high level of production. In this way the fishery may be maintained at relatively high intensity year after year.

Available evidence indicates however that production of salmon—as evidenced by return from sea—does not bear a strict relationship to the extent of spawning, i.e., the seeding in the preceding cycle year. Although within certain limits and under normal conditions the greater the seeding the more fish are produced—Rounsefell (1949) reports for the Fraser River sockeye that "50 percent of the variation in the run is due to variation in the escapement"—it can nevertheless occur that a relatively low or poor run will result from a large seeding; conversely there may be an exceptionally good return from a relatively light seeding. Such has been the experience at Karluk Lake, Alaska (Barnaby, 1944). Furthermore as any seeding increases beyond the capacity of (1) the good redd areas to accommodate the eggs, (2) the lake nursery areas to develop the young fish or (3) the ocean pasturage to meet demands of the fish from smolt to adult size, the rate of production will decrease. If, in any of the above three stages, the conditions should happen to be unusually unfavourable for survival, production may be very seriously affected.

Heavy losses in sockeye occur during the early freshwater period of the life-cycle, from egg deposition to emergence of the fry, during fry migration from

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stream to lake, and during the period of residence—one or two years—in the lake. Climatic and environmental (stream or lake) conditions play an important part and, owing to the great variability of these from year to year, the production of young sockeye may fluctuate widely. It would seem much more appropriate, therefore, to relate the return of adults from the sea to the numbers of seaward-migrating smolts, if, as is commonly supposed, conditions in the ocean are more stable and mortality less variable.

Although *numbers* of seaward-migrating sockeye (smolts) are important in determining the numbers of returning adults from the sea, it has seemed likely that the *size* of the young migrants might also have a bearing upon the extent or percentage of adult return. In order to explore this probability and assess its importance the following data are presented.

SMOLT MIGRATIONS AND ADULT RETURNS

From studies at Cultus Lake, B.C., by the Fisheries Research Board of Canada during the period 1925 to 1938 (Foerster, 1938; Foerster and Ricker, 1941), some phases of which were continued by the International Pacific Salmon Fisheries Commission to 1946, information is available on the smolt migrations from the lake each year from 1927 to 1944 and on the returning spawning runs of three-, four- and five-year adults. These data are given in Table I, together with records of the average weight and length of the smolts each season. The smolt run each year consisted of varying proportions of one- and two-year individuals, the former generally predominating. The weights in grams and the lengths in centimetres of each age-class were averaged and weighted as to relative abundance. For the years 1936 to 1938 the weights were estimated from mean length records.

It was originally considered that weight would be a better indication of size and general virility or condition than length. Furthermore, for correlation purposes the greater variations in mean weight (2.7 grams to 12.8 grams) might demonstrate more clearly the probable relationship of size to percentage adult return than length (6.3 cm. to 10.7 cm.). However an analysis of the relationship of *length* to percentage adult return reveals that the correlation is quite as good, in fact slightly better. If predation in the stream below the counting weir or in the Fraser estuary or in the ocean is an important cause of mortality, (discussed below), it could be that length of smolt, as a measure of activity of the fish and ability to elude its predator, could be more significant than weight. Nevertheless since weight, as a measure of size of smolt, is probably a better indicator of smolt production (kilograms of smolt produced in the lake), it is retained as a size indicator in the correlation calculations.

The adults returning to Cultus Lake represent the spawning escapement only—that portion of the run that passes successfully through the fishing areas. There is no record of the number of Cultus Lake–bred sockeye taken by the commercial fishery each year, but the data for two years when such records were obtained, 1931–33 and 1932–34 (Foerster, 1936, p. 31), showed that the commercial fishery removed 52 and 75 per cent, respectively, of the total Cultus

Lake population. The spawning escapements represented, therefore, 48 and 25 per cent of the inbound stock.

In some of the years a proportion or all of the smolt migrants were marked by removal of certain fins. This produced a differential mortality (Foerster, 1936) which was calculated at 62 per cent. The return of adults in those years when marking was undertaken would therefore be appreciably reduced. For such years, consequently, the actual adult returns were increased by the factor ($\times$ 2.632) to allow for mortality due to marking. It is realized that the mortality rate may have varied considerably from year to year but no more precise weighting procedure is available. As a matter of fact, correlations were also calculated eliminating the four years when all the smolts were marked. The differences found between the coefficients for the 14 years and those for the full 18 seasons were such that they would have caused little change in the general picture. Therefore the full series of data (18 years) was used.

It might be anticipated, in view of the possible or probable year-to-year fluctuations in the commercial fishing drain on the Cultus Lake run of sockeye, that any relationship which might exist between abundance or size of seaward migrants and percentage return of spawners would be so obscured as to be

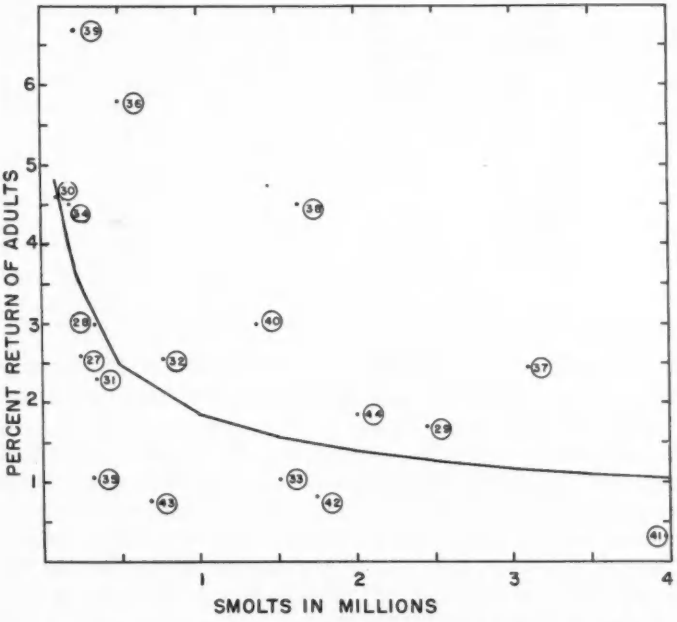

FIGURE 1. The percentage return of adult sockeye salmon to Cultus Lake from smolt migrations of varying magnitudes, as calculated from a log-log treatment of actual data (Table I). Equation of curve: $\log y = 0.674 - 0.4076 \log x$. Each year's relationship (1927–1944) is plotted.

difficult to demonstrate. A significant inverse correlation *is* found, however, between logarithms of number of migrants and logarithms of percentage adult return (Figure 1). Its magnitude is —0.53, which closely approaches the 2 per cent level of significance. It is the purpose of this paper to assess the factors which contribute to this correlation.

TABLE I. Records of sockeye smolts counted out of Cultus Lake each year and the three-, four- and five-year-old adults returning therefrom in the spawning escapement. The average length in centimeters, and average weight in grams, of the migrants are also shown.

Year of smolt migration	Number of smolts	Average length	Average weight	Total returning adults	
				Number	Percentage of smolts
1927	249,700	10.07	11.0	6,364	2.56
1928	336,200	8.08	5.1	10,910	3.25
1929	2,459,800	6.86	3.1	39,835	1.62
1930	104,100	10.70	12.8	4,808	4.61
1931	365,300	9.08	7.3	7,613	2.08
1932	779,000	9.02	7.3	20,228	2.60
1933	1,566,100	7.22	3.7	16,103	1.03
1934	183,700	8.66	8.4	8,522	4.64
1935	323,900	9.26	8.2	2,703	0.83
1936	497,600	9.80	8.9	28,800	5.78
1937	3,112,000	8.42	5.8	75,584	2.43
1938	1,639,900	8.8	7.0	73,629	4.50
1939	217,000	10.5	12.8	14,469	6.68
1940	1,374,800	9.9	9.7	41,146	2.99
1941	3,979,000	6.3	2.7	12,173	0.31
1942	1,752,500	8.1	5.4	14,084	0.80
1943	694,100	9.2	7.8	5,198	0.75
1944	2,012,000	8.9	7.5	37,281	1.85

FACTORS AFFECTING THE RETURN OF ADULTS FROM SMOLT MIGRATIONS

The percentage return of adults from known smolt migrations may be influenced by (*a*) the numbers of fish in the smolt run and (*b*) the size of the smolts. It could be that:

(1) a larger number of smolts would suffer less predation during seaward migration and in the sea than a smaller number because the predator population (fish and birds) may be more or less stable from year to year, and in years when smolts are very plentiful the predators may become quickly satiated and thus take proportionately fewer from the run; or

(2) a larger number of smolts would attract more predators to the stream and thus lead to a heavier predation; or

(3) a large smolt migration would result in a large return of adult sockeye from the sea and encourage fishermen to fish longer in the season than when Cultus sockeye are less abundant, thus substantially reducing the per-

centage spawning escapement. (The Cultus Lake run is latest to pass through the Fraser fishery.)

Since it has already been shown (Foerster, 1944) that the larger the smolt migration the smaller the size of the smolts, it could be that the *size* of the migrants is the main factor in ocean survival and percent return of adults and that either:

(4) small smolts may be more vulnerable to predation than larger ones, by reason of the facts that they may swim less actively, may dodge predators less readily, may be available to a greater size range of predators, a greater number of them may be necessary to satisfy a predator's appetite or capacity, or they may withstand less successfully the transfer from fresh- to salt-water habitat in the river estuary; or

(5) large smolts may be more abundantly taken by predators because they attract predators from a greater distance, are less active, proportionately, than smaller individuals, and may be less virile in general.

In order to assess the possible significance of these various factors correlation relationships were determined, using logarithmic data in every case, since (1) they offer better comparisons of ratios, (2) they make the variance of observations more uniform and (3) they gave slightly higher "R" values. The coefficients were:

	Factors related	*Coefficient of correlation*	*Confidence level (P)*
I	Number of smolts— Number of returned adults	+0.6789	$<.01$
II	Average smolt weight— Number of returned adults	−0.2252	$>.05$
III	Average smolt length— Number of returned adults	−0.1440	$>.05$
IV	Number of smolts— Percentage adult return	−0.5324	$<.05$
V	Average smolt weight— Percentage adult return	+0.6582	$<.01$
VI	Average smolt length— Percentage adult return	+0.83	$<.01$

It is only to be expected that as the number of smolts passing to sea increased, the number of resulting adults returning from the sea would also be greater in numbers (I above) though not necessarily greater as a percentage of smolt migration (IV above). It is apparent that the effects of both number of migrants and size are involved in the correlations and must be separated out by calculating partial correlations.

For *weight* of smolts the partial correlations have been worked out to determine the influence, on the number of returning adults to Cultus Lake, of (A) the number of smolts when the average weight is kept constant and (B) the average weight when number of smolts is kept constant. They are:

$$A: 0.7674 \ (P < .01)$$
$$B: 0.5255 \ (P = .03)$$

From the equation $\hat{Y} = 0.9399X_1 + 1.1841X_2 - 0.6160$, where $\hat{Y}$ = log number of returning adults, X_1 = log number of smolts, and X_2 = log average weight of smolts, Figure 2 has been prepared, showing, for various calculated smolt migrations, the number of returning adults to be expected according to the average weight of the smolts. It will be noted that the larger the smolts (weight) the greater the number of returning adults.

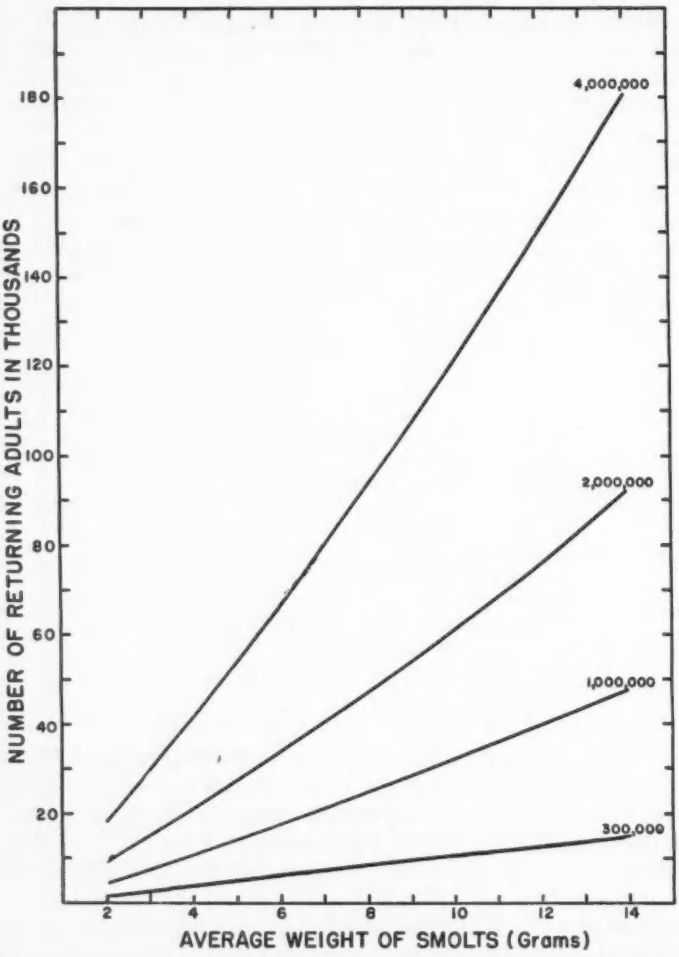

FIGURE 2. The number of adult sockeye returning to Cultus Lake from specific smolt migrations according to the average weight in grams of the smolts.

The standard regression coefficients (Snedecor, 1946, p. 342) from which the above equation was calculated are 1.0836 for number of smolts and 0.5591

for average weight of smolts. The standard error of both coefficients is 0.2337. Combined with the correlation coefficients I and II, elsewhere above, respectively, the regression gives an estimate of the multiple correlation, namely, $R = 0.7809$, $R^2 = 0.61$, $R^2_A = 0.56$. Thus 56 per cent of the variability in the size of adult runs is associated with the combined variation in number of migrants and size (mean weight) of migrants.

In Figure 3 the relationship is shown as the percentage return of adults calculated from the numbers of smolts migrating to sea, as taken from Figure 2. It very clearly demonstrates that size (weight) of smolts is an exceedingly important factor in the subsequent survival of smolts during migration downstream to the ocean and during ocean residence.

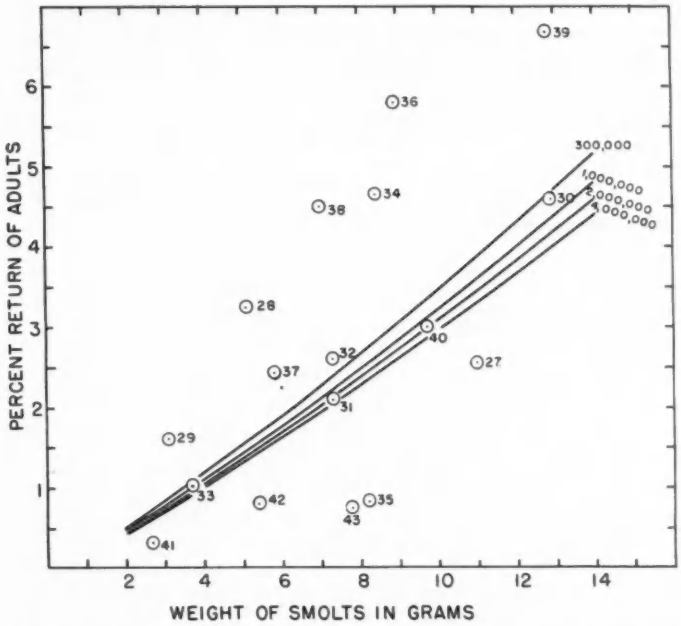

FIGURE 3. Variation in percentage return of adult sockeye salmon from four levels of smolt seaward migration according to average weight of smolts. Each year's actual percentage return, as taken from Table I, is shown.

For *length* of smolts, the partial correlations were found to be: (C) number of returning adults to Cultus Lake on number of smolts when the average length is kept constant: 0.8315 ($P < 0.01$); (D) number of returning adults on the average length of smolts when the number is kept constant: 0.6630 ($P < 0.01$).

Standard regression coefficients were calculated as 1.1755 for number of smolts and 0.6954 for average length of smolts, with standard error of ± 0.2027 for each. The multiple regression of number of adults on length of smolts and

number of smolts was R = 0.8354, from which $R^2_A = 0.6576$ (Snedecor, 1946). Thus 66 per cent of the variability in the size of the adult runs is associated with the combined variation in number of migrants and size (mean length) of migrants, a somewhat higher percentage than was obtained when using mean weight as the size indicator.

In Figure 4 is shown the relationship of percentage return of adults to the average length of smolts when smolt populations are 300,000 and 4,000,000, respectively. For comparison the original curve of percentage return of adults to average length of smolts with population varying from year to year, as shown in Table I, is included.

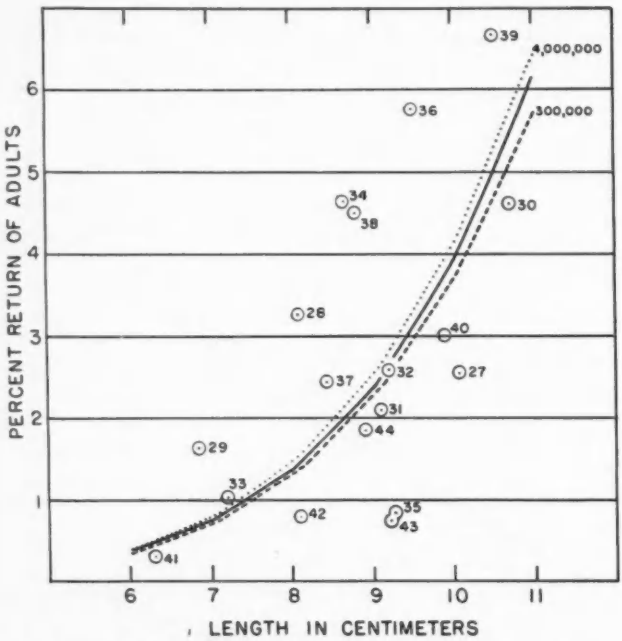

FIGURE 4. The percentage return of adult sockeye salmon from two levels of smolt seaward migration according to average length in centimetres of the smolts. The solid curve represents the original regression curve of percentage return to average length of smolts ($\log y = 4.13275 + 4.7258 \log x$). Each year's actual percentage return of adults is shown in relation to average length as indicated in Table I.

CONSIDERATION OF THE INFLUENCE OF COMMERCIAL FISHING INTENSITY

The adult sockeye salmon returning to Cultus Lake represent that portion of the Cultus Lake population which escapes the commercial fishery in the Strait of Georgia and the Fraser River. Their numbers could obviously be materially affected by the extent and intensity of that fishery. From a certain smolt migra-

tion the percentage return of adults would be *high* if the commercial fishing effort were low or if the season were short, since Cultus Lake fish were found (Foerster, 1936) to be passing through the Fraser River fishery quite late in the fishing season; conversely, the percentage return of adults to Cultus Lake would be *low* if the fishing effort were high and the period of fishing a lengthy one, as could have taken place in the years 1938, 1942, and 1946, when the large and relatively late Adams River sockeye run occurred or in years of large pink salmon runs on the Fraser, which are always the odd-numbered years.

In an attempt to arrive at some understanding or appreciation of the effect of commercial fishing effort upon the Cultus Lake sockeye spawning escapement the differences between the logarithms of actual adult returns, and of calculated adult returns (as computed from the equation, p. 344), were determined (Table II). They have been plotted, in Figure 5, above and below a zero line, and it is indicated for each plot whether in that year the commercial sockeye pack was above (solid circles) or below (open circles) the mean pack for the period. It is also indicated in what years pink salmon runs (P) occurred (the odd years) and when the heavy and relatively late Adams River sockeye runs (A) took place.

TABLE II. Showing the difference, for each year's return of adults to Cultus Lake, between log actual return and log calculated return.

Year		Log actual	Log calculated	
Smolt run	Adult return	adult return	adult return[a]	Difference
1927	1929	0.8038	0.9895	−.1857
1928	1930	1.0378	0.7194	+.3184
1929	1931	1.6003	1.2715	+.3288
1930	1932	0.6819	0.7144	−.0325
1931	1933	0.8816	0.9308	−.0492
1932	1934	1.3060	1.2402	+.0658
1933	1935	1.2068	1.1819	+.0249
1934	1936	0.9305	0.7267	+.2038
1935	1937	0.4319	0.9544	−.5225
1936	1938	1.4594	1.1632	+.2962
1937	1939	1.8785	1.6913	+.1872
1938	1940	1.8669	1.5265	+.3404
1939	1941	1.1605	1.0113	+.1492
1940	1942	1.6143	1.6224	−.0081
1941	1943	1.0852	1.3985	−.3133
1942	1944	1.1485	1.4202	−.2717
1943	1945	0.7159	1.2371	−.5212
1944	1946	1.5714	1.6455	−.0741

[a]Calculated from formula, p. 344.

In relation to the Fraser River sockeye packs in general, the actual Cultus Lake returns were less than the calculated (i.e., below the zero line) in seven years when the Fraser packs were below average and in two years when they were above average. In other words, in the seven years when the fishing (as represented by the pack) was below average and therefore the escapement to

Cultus Lake might have been expected to be *greater* than calculated, the actual return was *less* than the calculated one. Only in two of the years when packs were above average did the actual escapement prove to be less than calculated. Similarly, the actual returns were greater than the calculated (i.e., above the zero line) in five years when the Fraser River packs were below average for the period of years (as might have been expected to occur if the fishery had an undue influence) and in four years when the packs were above average (which should not have occurred if the fishery had an unexpected influence on the Cultus Lake run of sockeye). The interpretation would be, therefore, that if the

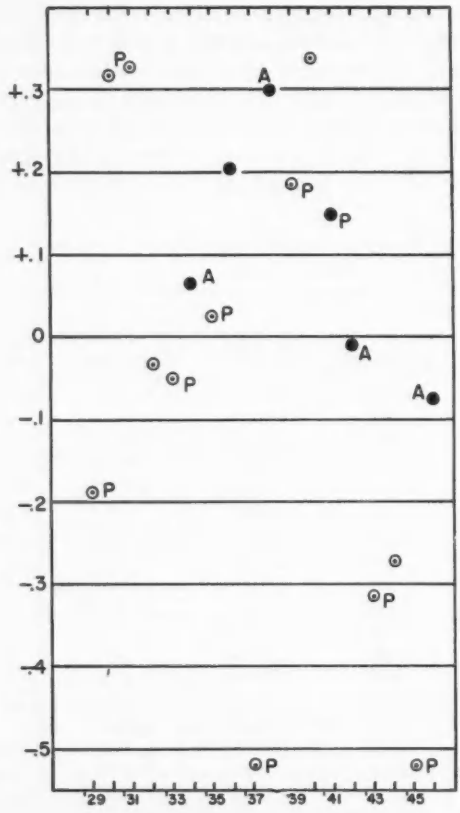

FIGURE 5. The differences between log actual return of adult sockeye salmon to Cultus Lake and log calculated adult return plotted above or below a zero line. For each year the Fraser River commercial sockeye pack is indicated as above (solid circles) or below (open circles) the average for the 18-year period (1929–1946). It is also indicated which years were pink salmon years (P) and in which years the heavy and relatively late-season Adams River sockeye runs (A) occurred.

commercial pack is any indication of the extent of the Fraser sockeye fishing, it has had little influence on the percentage return of the Cultus Lake population to its spawning area.

For those years when the late Adams River sockeye run occurred (which years might, through later season fishing, have taken a greater proportion of Cultus Lake–bound fish), the actual Cultus Lake return was greater, not less, than that calculated in two years out of four, and was quite appreciably greater in one season, 1938. The late sockeye fishing years of Adams River runs seems not to have removed any extra proportion of Cultus Lake sockeye.

For those years when pink salmon fishing of appreciable magnitude occurred–the odd years–the actual Cultus Lake returns were less than the calculated in five seasons out of nine. From the record of pink salmon packs,[2] it is known that these five years (1929, 1933, 1937, 1943, 1945) were not always those in which *large* pink salmon packs were made and which might therefore be considered as seasons of heavy and long fishing. In 1939 and 1941, when the actual sockeye spawning escapements to Cultus Lake were greater than the calculated, the pink salmon packs were quite good. In the years 1937 and 1945 when the actual sockeye returns to Cultus Lake were considerably less than the calculated, the pink salmon packs were no greater than in 1939 and 1941. The commercial packs are not too accurate an indication of extent of fishing effort, intensity or length of season but they are at least indicative in a general way. It would seem, therefore, that the sockeye escapements to Cultus Lake were usually not unduly reduced by the commercial fishery for pink salmon. The very wide differences in 1937 and 1945 might suggest, however, that in some "pink" years there may be some effect on escapement of Cultus Lake sockeye.

The discrepancies shown in Table II between log of actual returns and log of calculated returns are obviously the result of some influencing factors. The data suggest that known large-scale variations in fishing effort are not responsible. They may be the result of year-to-year differences in the actual removal by the commercial fishery of Cultus Lake–bound sockeye or the extent to which a portion of the late Cultus Lake run coincides with the extended autumn "closed" season, when sockeye fishing on the Fraser River is prohibited. The differences may be caused also by the varying extent of the net fishery by Indians at the confluence of the Fraser and Vedder Rivers, into the latter of which the outlet stream from Cultus Lake empties, or they may be due to year-to-year differences in ocean survival of the Cultus Lake population.

CONCLUSIONS

The evidence presented shows clearly that survival of sockeye during seaward migration and ocean residence depends greatly on the size of the smolts at migration time. It would seem, then, that the factor of greater loss of small migrants during down-stream migration and in the ocean is an important one

[2]1929, 158,208 cases; 1931, 13,307 cases; 1933, 92,746 cases; 1935, 111,328 cases; 1937, 94,010 cases; 1939, 95,176 cases; 1941, 102,388 cases; 1943, 29,860 cases; 1945, 95,748 cases. From statistics published by the B.C. Department of Fisheries.

although it need not represent the only loss factor. The distance from Cultus Lake to the Fraser River estuary is only approximately 60 miles, including one mile of Sweltzer Creek, the outlet stream from Cultus Lake, 15 miles of the larger Vedder River and around 54 miles of the Fraser itself. This is a relatively short seaward journey for young sockeye. Therefore if predation during seaward migration is an important factor in causing mortality of smolts and reducing the return from a known smolt migration, it could be appreciably greater in areas where much longer stretches of tributary stream or main river have to be traversed from lake to sea. Other possible mortality factors, such as loss during the period of transition from fresh to salt water habitat, or loss during ocean residence, would presumably affect all populations equally.

SUMMARY

Data are available from Cultus Lake giving (*a*) the number of seaward-migrating smolts for each year from 1927 to 1944, (*b*) the mean size of the smolts and (*c*) the number of adults produced from each smolt seaward migration returning in the spawning escapement to the lake.

Analysis of these data indicates a negative correlation between size of migration (in number of smolts) and percentage return of adults which is found (by multiple correlation treatment) to be related principally to the size (weight in grams) of the smolts.

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Dr. W. E. Ricker has been for many years associated with the Cultus Lake studies and has contributed greatly in the collection and analysis of data and results. Grateful acknowledgment is made of his advice and assistance in the preparation of this paper, particularly in the statistical treatment of the data. Thanks are also extended to Dr. A. L. Tester, now of the University of Hawaii, for his interest and advice.

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Migrations of Spiny Dogfish Tagged in Newfoundland Waters[1]

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ABSTRACT

Tagging of 279 spiny dogfish (*Squalus acanthias*) near St. John's, Newfoundland, July 9 to 23, 1942, gave 5 per cent recaptures: 4 returns in 1942, 5 in 1943 and, apart from 1946, one in each successive year until 1949. Eight recaptures were from Newfoundland, 3 from the Maritime Provinces, 2 from Gloucester, Massachusetts, and one from Virginia.

INTRODUCTION

Newfoundland fishermen find dogfish a considerable hindrance to their cod fishing, particularly in the long-line and hand-line operations. Dogfish are not used commercially in Newfoundland. In 1938, in a collection experiment for reduction of dogfish to meal and to determine the results of fairly intensive fishing, the Government of Newfoundland purchased two or three million dogfish, weighing over ten million pounds, in Placentia Bay, Newfoundland, without any apparent diminution of supply. Since it is obviously too great a task for Newfoundland to control dogfish populations unless these populations are local rather than international in nature, studies of dogfish life-history including migration were carried out in 1942 at St. John's.

Manzer (1946) reports, for a *Squalus acanthias* of the Pacific coast tagged by the Pacific Biological Station, a migration of 1,100 miles in 171 days from the Queen Charlotte Islands to Santa Cruz, California. (The Pacific stock was formerly called *Squalus suckleyi*, but Bigelow and Schroeder (1948) were unable to distinguish it from *acanthias*.)

Bonham *et al.* (1949) give an account of tagging of the Pacific *Squalus acanthias* off the coast of the state of Washington. These fish were tagged with plastic Petersen disc tags. Over 4,000 dogfish were tagged, mostly in 1942 and 1943, with recoveries of tags up to August, 1944, amounting to 6 per cent. Some tagged fish migrated as far south as northern California or as far north as Vancouver Island, with distances at recapture from zero to 760 nautical miles from the tagging area.

There is a record of S. *acanthias* tagged in Washington by the Washington State Fisheries Laboratory and recaptured seven and a half years later in Tsugaru Strait, Japan, over 5,000 miles distant (Anon., 1952).

Mr. W. E. Barraclough of the Pacific Biological Station in a recent private communication says that a Petersen celluloid disc tag has been chiefly used in all these tagging experiments. The discs were attached either through the snout or through the base of the first dorsal fin just behind the spine.

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PROCEDURE

In 1942, from July 9 to 23, 279 spiny dogfish (*Squalus acanthias*) from a salmon gill-net were tagged by the author, 30 to 60 yards offshore at Sugar Loaf Point, 3½ miles north of St. John's, Newfoundland. Tags of bright red cellulose nitrate 32 mm. long and 8 mm. broad (1¼ by 5/16 inches) were attached by one end to a 0.81-mm. (0.032-inch) diameter nickel wire. The wire was inserted through the flesh and the base of the spine anterior to the first dorsal fin. A large hypodermic needle was used in the tagging operation. A figure showing the attached tag and a preliminary account of recaptures during the years 1942–43 have been published (Templeman, 1944). Dogfish are very hardy and there was little difficulty in tagging them beyond making sure that an assistant held the head and tail firmly.

RECAPTURES

Table I gives a summary of sizes and sexes tagged and recaptured and the year of recapture. Table II and Figure 1 show places and dates of recapture. Four dogfish were caught in 1942, the year of tagging, five during the next year and, apart from 1946 when no tags were returned, one in each succeeding year until 1949, over seven years after tagging. In view of the serious corrosion noted by Calhoun, Fry and Hughes (1951) for nickel pins, and to a lesser extent for nickel wire, used for tagging in California, it is worth mentioning that tags remained on the fish as long as five, six and seven years. Of four wires returned, three recaptured in 1943 showed no evidence of corrosion, while on one returned in 1948 there may have been a very small amount of surface corrosion which yet revealed bright metal when it was slightly scraped. Even in the latter case there appeared to be no reason why the wire and tag should not have remained attached for another six years or more.

Since dogfish on the Atlantic coast are non-commercial, are only caught incidentally to other fisheries and are only occasionally taken on board the fishing boat, the total recaptures of 5 per cent and the long period over which recaptures

TABLE I. Dogfish recaptures from tagging near St. John's, Newfoundland, July 9-23, 1942

Length range	No. tagged			Females recaptured and year of recapture								Total recaptures
	Male	Female	Total	1942	1943	1944	1945	1946	1947	1948	1949	
cm.												
66– 70	1	...	1	...	...	...	...	...	...	...	...	0
71– 75	1	10	11	...	...	...	...	...	...	...	...	0
76– 80	6	49	55	...	1	1	...	...	...	...	...	2
81– 85	2	82	84	3	2	...	...	...	...	...	1	6
86– 90	...	85	85	...	1	...	...	...	1	1	...	3
91– 95	...	39	39	1	1	...	1	...	...	...	...	3
96–100	...	3	3	...	...	...	...	...	...	...	...	0
106–110	...	1	1	...	...	...	...	...	...	...	...	0
TOTAL	10	269	279	4	5	1	1	0	1	1	1	14

TABLE II. Recaptures from dogfish tagged near St. John's, Newfoundland, July 9–23, 1942.

General location	Position of capture	Year	Date	Size of female when tagged
				cm.
Nfld. north of tagging point	Job's Cove Bight	1942	July 25	95
	Change Islands, N. D. Bay	1942	Aug. 18	82
	C. Freels, Gull I., Bonavista Bay	1943	Aug. 2	92
	Tilting, Fogo	1943	Sept. 6	84
	Baccalieu, N. D. Bay	1944	Sept. 11	79
Nfld. south of tagging point	Grey River, Ramea	1942	Aug. 27	81
	Pushthrough, Hermitage Bay	1945	June 14	93
	Little Hr. East, Placentia Bay	1948	Sept. 1	86
Maritime Provinces	Shippigan I., N.B.	1943	Sept. 11	88
	Cheticamp Pt., Cape Breton I., N.S.	1943	Nov. 4	83
	Strait of Canso, N.S.	1949	Sept. 13	84
United States	14 miles ENE Thatcher's I., Mass.	1942	Nov. 23	85
	25 miles off Gloucester, Mass.	1943	Dec. 4	78
	50 miles E. by S. Cape Henry, Virginia	1947	Feb. 14	88

were made indicate that the tagging method was probably efficient. No males were recaptured but less than 3 per cent of the tagged animals were males. The last recovery was in 1949, so it is unlikely that further recaptures will be made.

MIGRATIONS

Of the 14 recaptures eight were from Newfoundland, five north and three south of the tagging area, and three were caught in the northern Maritime area from the Strait of Canso to Shippigan Island. The latest recapture was from the Strait of Canso in September, 1949, over seven years after tagging.

Of the three United States recaptures, two were obtained at Gloucester, Mass., one in late November in the year of tagging and one in early December of the following year. The third recapture was by a trawler operating off Cape Henry, Virginia, on February 14, 1947, over five years after tagging. The first recapture off Gloucester had travelled over 900 miles in 132 days. The Virginia recapture was over 1,300 miles from the tagging area.

In the St. John's area in 1942 the smallest mature female dogfish was 74 cm. From 76 to 80 cm. 60 per cent, from 81 to 84 cm. 92 per cent, from 85 to 88 cm. 98 per cent and above 88 cm. all of the females were mature. Although it was possible to determine only the sex and not the maturity of the females tagged, it is indicated that most of the tagged fish were mature females carrying young, and the recaptures show a southward late fall movement of some at least of these large pregnant females, with presumably a compensating northward movement

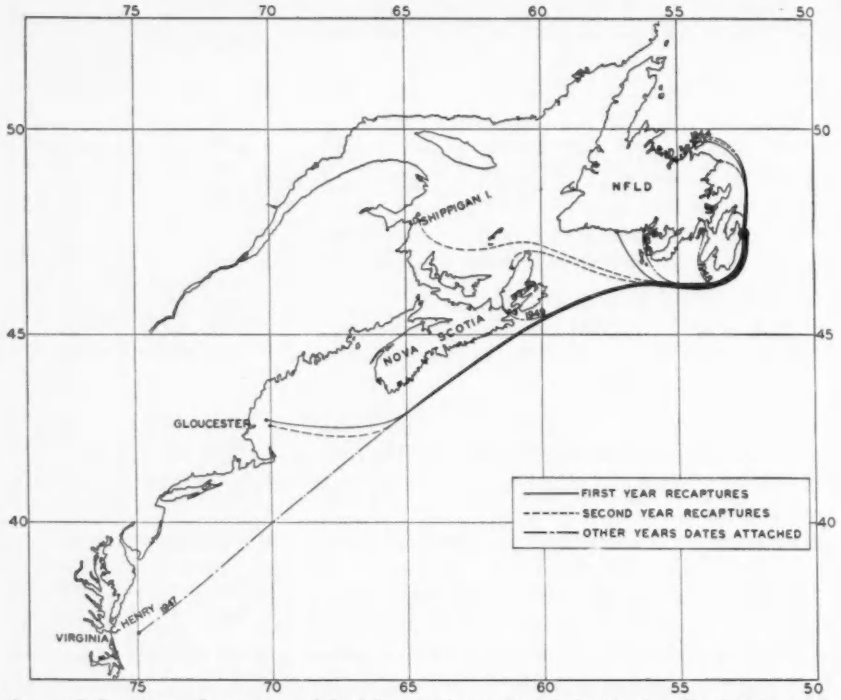

FIGURE 1 Locations of recapture of dogfish tagged near St. John's, Newfoundland, July, 1942.

in the spring and early summer. The distant recaptures are also numerous enough, considering the small number tagged, and occur in enough different years, to show that even if there is not indeed a single population there is at least a widespread intermingling of the populations of adult female *Squalus acanthias* on the Atlantic coast of North America.

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Preparation of Cod Liver Residues and Vitamin B_{12} Concentrates[1,2]

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ABSTRACT

As the first part of an investigation of the nutritive value of cod liver, two methods of preparation of cod liver residue were studied, as well as the effect of drum drying the residue, with and without the presence of sodium bisulphite, defatting the dried residue and extracting vitamin B_{12} from the dried residue.

It was found that Vandenheuvel's method of preparation of residue produces very good results. The fresh residue could be dried without appreciable loss of vitamin B_{12} activity on a double drum dryer, operated with steam at 20 p.s.i.g. Sodium bisulphite afforded some protection during the drying. The most satisfactory results in defatting were obtained by extraction with dichloroethylene. Concentrates with vitamin B_{12} activity equivalent to 2–4 micrograms per milliliter were produced by extraction of dried, defatted residue with water and evaporation *in vacuo*.

Five different types of residue were prepared for further studies.

A few years ago, a new process was developed in this laboratory (1) by means of which cod liver oil could be separated from the liver residue without harsh chemical treatment of the raw material. In this process, which only involved mincing of the livers, heating the homogenate at pH 8.5 to 60°C., and centrifuging, a proteinaceous residue was obtained that contained virtually all the B-vitamins originally present in the livers (2). Such a residue was expected to possess high nutritional qualities and might be used for a variety of purposes: feeding of farm animals, preparation of vitamin concentrates.

With this purpose in mind, methods of preparing the residue in a form suitable for practical usage were studied. Special attention was paid to the vitamin B_{12} content of the preparations, because of the importance of this vitamin as a part of the "animal protein factor" complex.

This work was the first part of an extensive investigation into the nutritive value of cod liver residues.

EXPERIMENTAL

Materials

For small scale experiments, fresh livers could usually be obtained, i.e. livers removed from fish that had not been from the water longer than 12 hours. When larger amounts were required, they were collected aboard a trawler during the last few days of her fishing trip. The livers were never older than three days;

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[2]Paper No. 1 of a series: "The Nutritive Value of Cod Liver".

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during the trip, they were kept cool, if possible under ice. The raw material was always in a good condition; the tissues were firm, and no spoilage was apparent.

Methods

PREPARATION OF FRESH RESIDUE. Two methods of preparation were used: A, the standard procedure developed by Vandenheuvel (1), and B, an autoclaving process not involving the use of alkali. The following were the details of the procedures.

A. Five hundred grams of liver was minced in a Waring blender, then warmed in a waterbath until the temperature reached 60°C. To the homogenate an amount of 7 normal sodium hydroxide (approximately 5 ml.) was added, sufficient to produce a residue with pH 8.0–8.5. The mixture was then centrifuged, the oil and residue were collected, and the latter was brought to pH 6.0–6.5 with 4 normal hydrochloric acid.

B. Five hundred grams of liver was minced in a Waring blender and warmed in boiling water until the temperature was 85°C. The sample was then placed in a pressure cooker which was heated quickly until the pressure reached 10 p.s.i.g. (115.2°C.). The heat was turned off and the sample left to cool to 100°C. The mixture was centrifuged while still hot; the oil and the residue were collected.

DETERMINATION OF THE VITAMIN B_{12} CONTENT OF RESIDUES. Total vitamin B_{12} activity was determined by microbiological assay with *Lactobacillus Leichmannii* (A.T.C.C. 4797). The basal medium was that described by Peeler et al. (3). Standard curves were established with a solution of crystalline vitamin B_{12} in water. The final volume per assay level was 10.0 ml.; each level was run in triplicate. For routine work all solutions were pipetted with a modified Cannon Automatic Dispenser (4).

Samples of fresh liver residue (approximately 3 g.) were diluted with three times their volume of water and 1 mg. of sodium bisulphite per gram of sample was added (5). The mixture was autoclaved for five minutes at 5 p.s.i.g. (108.4°C.), cooled, diluted with water to 100 ml., and filtered through Whatman No. 1 filter paper. The filtrate was diluted with water to contain about 100 $\mu\mu$g. of vitamin B_{12} per ml.; this solution was used in the assay.

Essentially the same treatment was given to samples (about 1 g.) of dried residue. The only difference was in the initial amount of water, which was increased to ten times the weight of the sample.

QUALITATIVE ANALYSIS OF GROWTH FACTORS WITH VITAMIN B_{12} ACTIVITY. Ascending paper strip chromatography was used for qualitative analysis of the mixture of growth factors with vitamin B_{12} activity present in the extracts of liver residues. Twenty microliters of the solution to be analysed was spotted on a paper strip (Whatman No. 1, 10 x 465 mm.), 20 millimeters from the end. Chromatography was carried out using the system n-butanol/water. Spots, present on the paper after chromatography, were located by the technique of bioautography described by Winsten and Eigen (6). The medium was Bacto-CS Vitamin B_{12} Agar[3]; the organism *Lactobacillus Leichmannii* (A.T.C.C. 4797).

[3]Difco Laboratories Inc., Detroit, Michigan, U.S.A.

Results

Preparation of fresh residue. The standard and autoclaving procedures for the preparation of fresh residue were compared. Table I lists representative data regarding yield and composition of the products obtained.

Table I. Comparison of standard and autoclaving procedures for the preparation of cod liver residue.

Procedure	Amount of liver used	Yield of oil		Yield of residue		Solids in residue	Fat in residue	Vit. A in oil
		a	b	a	b			
	g.	g.	%	g.	%	%	%	IU./g.
Standard	492	142	28.9	350	71.1	38.5	12.1	4450
Autoclave	480	155	32.3	325	67.7	39.3	8.2	5650

It may be seen that the removal of oil in the autoclaving procedure was slightly better than in the standard procedure and that the vitamin A content of the oil was considerably higher. The solid contents of the two types of residue were practically the same, and the fat content was slightly higher for the standard method.

The vitamin B content of the residue obtained in the autoclaving process was higher than that of the product of the standard procedure. The results of vitamin determinations on the residues are given in Table II.

Table II. Vitamin B contents of liver residues.

Procedure	Thiamine	Riboflavin	Niacin	Pantothenic acid		Vit. B_{12}
				Total	Free	
	μg./g.	μg./g.	μg./g.	μg./g.	μg./g.	μg./g.
Standard	0.96	4.4	59	24	13	0.39
Autoclave	3.43	5.6	63	29	18	0.57

Drying of fresh residue. Several batches of fresh residue were dried on a Buflovak Laboratory drum dryer[4] (double drums, atmospheric); various steam pressures were used, and in each case the drum speed was regulated to the maximum speed with which dried products were obtained with a water content not above 5 per cent. The appearance and the vitamin B_{12} content were used as criteria of the usefulness of the procedure. The results of these drying experiments are given in Table III.

It was concluded that the temperature of the steam used for drying did not affect the vitamin B_{12} content of the product for pressures up to 40 p.s.i.g. Better products were obtained with the low pressures than with higher pressures. For

[4]Buflovak Equipment Division of Blaw-Knox Co., Buffalo, N.Y., U.S.A.

TABLE III. Effect of dryer temperature on the vitamin B_{12} content and the appearance of the residue.

Steam pressure used in drying	Temperature of steam	Vit. B_{12} of product	Appearance of product
p.s.i.g.	°C.	*μg./g.*	
20	126.0	0.57	light brown
30	134.5	0.56	light brown
40	141.5	0.57	dark brown
60	153.0	0.22	very dark

further work, 20 p.s.i.g. was chosen as the pressure with which to operate the dryer.

In view of the protection afforded by sodium bisulphite in the extraction of vitamin B_{12} for assay purposes, some experiments were carried out to determine whether the reducing agent could be used to advantage in drying. The results of these experiments are listed in Table IV.

TABLE IV. The effect of the presence of sodium bisulphite during drying.

Sample	Method of preparation	Amount of bisulphite added	Solids	Fat	Vit. B_{12}	Vit. B_{12} loss on drying
		mg./g.	%	%	*μg./g.*	%
Fresh residue	Standard	..	36.5	13.8	0.25	..
Dried "	"	0	96.5	39.9	0.57	13.5
Dried "	"	1.0	95.8	38.5	0.62	5.5
Fresh "	Autoclave	..	38.0	13.3	0.30	..
Dried "	"	0	95.2	37.4	0.63	16
Dried "	"	1.0	96.3	39.4	0.71	5.5

Drying in the presence of sodium bisulphite resulted in higher vitamin B_{12} contents of the residues; the effect of the agent was the same for the two types of residue.

DEFATTING OF DRIED RESIDUE. The keeping quality of dried residue, although much better than of the fresh product, was not satisfactory. Storage for three weeks at 1°C. allowed the samples to become rancid. This situation was considerably improved upon removal of the fats from dried residue by solvent extraction. Various fat solvents were tested on a small scale in a Soxhlet extractor: acetone, ethyl ether, 1,2-dichloroethane (dichloroethylene), hexane, and petroleum ether (boiling range 30–60°C.). All solvents were practicable; the most satisfactory results were obtained with hexane and dichloroethane. The latter solvent proved particularly useful for larger scale operation: 10 kg. of dried residue was stirred with 20 l. of solvent, and the mixture filtered through cheesecloth. This operation was repeated until the solvent was only very slightly coloured. The residue was then pressed as free from solvent as possible, and the

last traces of dichloroethane were removed by leaving the product, spread in thin layers, exposed to the air for 24 hours. A brown-yellow powder was obtained that could be stored at room temperature for at least six months without loss of vitamin B_{12} activity.

THE PREPARATION OF VITAMIN B_{12} CONCENTRATES FROM DRIED, DEFATTED RESIDUE. Extraction of vitamin B_{12} from dried, defatted residue was attempted in various ways, including batchwise extraction with different solvents or combinations of solvents and continuous extraction in a Soxhlet apparatus. The highest yields were obtained with water as the extractant; continuous extraction was most efficient.

The following were the results of a small-scale extraction: Five grams of dried, defatted residue, containing 0.57 μg. of vitamin B_{12} per gram, was extracted in a Soxhlet apparatus for one hour with 100 ml. of water. The extract contained 2.5 μg. of vitamin B_{12} (88 per cent of the initial amount), and the residue 0.085 μg. (3 per cent of the initial amount). Because the experimental error in the microbiological assay of vitamin B_{12} was rather large (5 per cent), these results indicated complete extraction.

Two methods of concentrating the aqueous extract were investigated: (i) lyophilization[5] and (ii) distillation *in vacuo*. The first method was expected to cause no losses of vitamin B_{12}; the second to be more rapid and convenient for laboratory work. Several samples of liver extract were treated. In all cases, lyophilization or distillation *in vacuo* (sample not heated over 50°C.) was continued until the moisture content of the sample was less than one per cent. It may be seen from the results, listed in Table V, that vitamin B_{12} losses were negligible for both processes. Distillation *in vacuo* was adopted for all further work. In practice the extracts were never evaporated to dryness but rather to a point where solids began to separate. The residue was then cooled and filtered. Concentrates were obtained with a total vitamin B_{12} activity of 2–4 μg./ml. and a solid content of 12–15 per cent.

TABLE V. The effect of evaporation on the vitamin B_{12} content of liver extracts.

Method of concentrating	Sample number	Amount of sample	Vitamin B_{12} of sample		Vit. B_{12} loss
			Initial	Final	
		ml.	μg.	μg.	%
Lyophilization	I	100	2.5	2.5	0
Distillation *in vacuo*	I	100	2.5	2.3	8
Lyophilization	II	100	20	19	5
Distillation *in vacuo*	II	1180	224	221	1.5

QUALITATIVE ANALYSIS OF GROWTH FACTORS WITH VITAMIN B_{12} ACTIVITY. For the qualitative analysis by paper chromatography, it was necessary to treat samples of residue in such a manner that the concentrations of the growth factors

[5]Lyophil Apparatus, Campbell-Pressman, Scientific Glass Apparatus Co., Bloomfield, New Jersey, U.S.A.

were high enough to surpass the lower limit of sensitivity of the test used to locate them on the paper. Essentially the procedure described above for the preparation of concentrates was used: three to five grams of residue was extracted with 10–15 ml. of water (autoclaved for 5 min. at 5 p.s.i.g.), the mixture was filtered, and the filtrate concentrated by lyophilization. The dry material was then taken up in a small amount of water and the resulting concentrate was subjected to chromatography. All types of residue (fresh, dried with and without the presence of sodium bisulphite, dried and defatted) were analyzed in this manner. The chromatograms showed the presence of vitamin B_{12} as well as of a number of other compounds with vitamin B_{12} activity. Drying or defatting did not alter the qualitative composition of the APF of the liver preparations. The compounds other than vitamin B_{12} were identified as desoxyribonucleosides of the following purines and pyrimidines: thymine, uracil, hypoxanthine, xanthine, and guanine.

Since it had been found that vitamin B_{12} exists in different forms (7), the nature of the vitamin in the cod liver preparations was established by chromatography on phosphate-treated paper according to Woodruff and Foster (8). The presence of vitamin B_{12} (cyanocobalamin) and of vitamin B_{12a} (hydroxocobalamin) was demonstrated.

DISCUSSION

Comparison of the standard procedure for the preparation of cod liver residue with a new, autoclaving process, indicated several advantages of the latter. For two reasons, however, the standard procedure was used when large amounts of residue (5 kg. and more) were prepared: (i) only the standard procedure had been tested on a laboratory scale as well as on a pilot plant and industrial scale (1), and (ii) the autoclaving method could be used only if the raw material was perfectly fresh; with livers that had softened, dark residues and very dark oils were obtained. The autoclaving method was used for the preparation of small samples of residue (about 500 g.).

Five types of residue were prepared in batches of 25 kg. each, for further animal experimentation. The description and composition are given in Table VI.

TABLE VI. Types of residue prepared for further study.

Type of residue	Solids	Fat	Vit. B_{12}
	%	%	μg./g.
Fresh	38.5	12.1	0.39
Dried without bisulphite	96.5	39.8	0.69
Dried with bisulphite	95.7	39.4	0.82
Dried without bisulphite, defatted	95.5	0	1.4
Dried with bisulphite, defatted	96.1	0	1.5

Vitamin B_{12} concentrates could be prepared from dried, defatted residue by extraction with water, and concentration of the extract by evaporation *in vacuo*.

Concentrates with a total activity of 2 μg./ml. were readily obtained. Further concentration would require much more complicated methods of purification. For the present investigation the concentrations obtained were sufficiently high.

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Stream Studies on Planted Atlantic Salmon[1]

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ABSTRACT

Plantings of Atlantic salmon fry were made in the Duffin Creek system in order to determine the survival and distribution of salmon under a variety of stream conditions. Population studies estimated that the three general June plantings resulted in an average survival of 12.7 per cent until the autumn of the first year, 9.2 per cent until the autumn of the second year. High summer temperatures were lethal to the salmon in certain parts of the creek system. Over the balance of the planted part, the greatest mortality occurred soon after plantings when heavy predation by other species of fish occurred. The extent of predation was determined largely by the amount of shelter available to the fry. Suitable shelter for the young salmon was limited generally to gravelly riffle areas where the degree of bottom sedimentation determined the amount of shelter offered. Other stream conditions were of minor or no importance in salmon survival. Further losses of salmon were low once the young salmon had become established in the creek system.

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INTRODUCTION

A study was carried out from 1944 to 1949 on the survival and distribution of Atlantic salmon (*Salmo salar*) fry which were planted in Duffin Creek, a southern

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Ontario stream flowing into Lake Ontario. This stream offered a very good opportunity to study the salmon in a stream system from which they had disappeared during the past century. The lack of native salmon permitted a ready determination of the effectiveness of each planting and allowed an analysis of the effect of varied and varying stream conditions on the welfare of the salmon.

This paper is divided into two parts. The first part, *Distribution Studies*, deals with the plantings of fry and the study of the subsequent survival and distribution until descent to the lake as smolts. The second part, *Factors Affecting Survival*, contains an analysis of the effect of stream conditions on the pattern of survival and distribution previously described.

The author wishes to express his sincere appreciation to Prof. J. R. Dymond, Dr. A. G. Huntsman, and Prof. F. E. J. Fry of the University of Toronto, for their valuable counsel during this research. Acknowledgment is given to Dr. W. J. K. Harkness, for his helpful guidance during the first years of the experiment and for the assistance given by the Fish and Wildlife Division of the Ontario Department of Lands and Forests under his direction. Financial assistance during the academic years of 1947–48 and 1948–49 was provided by two scholarships received from the Research Council of Ontario. The salmon used in the study were hatched from eggs provided by the Department of Fisheries, Ottawa.

I. Distribution Studies

DESCRIPTION OF DUFFIN CREEK

Morphometry and Nomenclature

The Duffin Stream system, located at lat. 44°N., long. 79°W., drains approximately 150 square miles of the southern part of Ontario County and flows into Lake Ontario about 20 miles to the east of Toronto. The system consists of two main branches which converge about four miles from the lake into a common stream. Each branch has several tributary streams as is shown in Figure 1.

Also shown in Figure 1 are the experimental sections into which the stream was divided. The two main branches, Duffin East and Duffin West, were divided into sections designated by roman numerals and numbering from the lake upstream so that similarly numbered sections of the two branches are more or less equidistant from the lake. The tributary streams of the east branch used in the study were named Duffin East 1, 2, 3, 4 and 5, and those of the west branch, Duffin West 1 and 2. These tributary streams were divided into experimental sections, a, b, c and d. Three experimental streams planted only in 1948 were named A, B and C.

Geology

Although the area drained by Duffin Creek is underlaid by the Billings shales of the earliest Ordovician strata, it is generally covered by more recent deposits. Exceptions are in sections III and IV of Duffin East where stream erosion has exposed the fossiliferous soft bituminous shale.

The area nearest the lake is a recent deposit of sand and gravel which gradually becomes thinner, grading into Iroquois clay about four miles from

the lake (Coleman, 1922). This in turn grades into the Iroquois sand and gravel ridges which pass through sections V and VI of both Duffin East and Duffin West. North of this ridge is an area of rich clay covered in certain areas with glacial drift. There are many drumlin hills characteristic of glacial topography in the upper part of the drainage basin.

As a result of extensive clearing of the woodlands for agriculture, the Duffin Creek drainage basin has been subjected to extensive erosion and spring flooding.

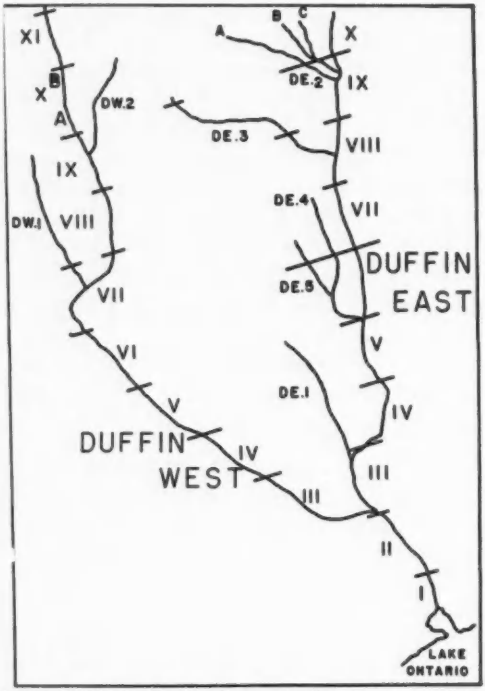

FIGURE 1. The Duffin Creek system, showing nomenclature.

GRADIENT

The gradient of the stream bed has been calculated from the topographical map prepared by the Geographical Section of the Department of National Defence. The slope of the bed over the lower four miles of the main stream through sections I and II is about 17 feet to the mile. The gradient then increases abruptly to about 50 feet to the mile and remains relatively constant, excepting local variations, to the source of both main branches.

FLOW

The surface velocity of the water under normal summer flow over 50 foot lengths of stream was determined at a number of locations on the stream system

by means of floating chips. Surface velocities were found to vary from a maximum of 2.9 feet per second in a part of section V of Duffin East down to ponds and pools where no surface velocity could be measured.

The lowest four miles of the main stream has a normal flow of about 1.5 feet per second until it widens into a marshy area. The actual entrance into the lake varies greatly in width and depth from time to time. The location of the opening itself may vary a hundred feet or more from one year to the next. Strong onshore winds may form a sandbar which closes the mouth entirely until the pressure of the stream water is sufficiently great to force an opening through the bar. This condition goes back at least to 1877, when Kerr (1877) reported that it was necessary to open the mouth of Duffin Creek eight times during the spawning season to ensure that salmon reached the spawning beds.

During the time of spring thaws and heavy rains extreme flooding is common. Even light summer rains cause a noticeable increase in the volume of flow in the lower parts of the stream system. For example, the normal volume of flow in section VI of Duffin East is 31.2 cubic feet per second. A three-day rain in June 1947 increased this flow tenfold to 327.6 cubic feet per second. This degree of flooding is greatly magnified during periods of spring thaws.

The small source streams generally have a steady flow for a short distance from their sources. Series of alternating pools and riffles characterize a large part of both main branches and tributary streams, except the lower part of the main stream which has a continuous flow with no riffles. The depth of the water in the riffly areas over the stream system seldom exceeds two feet and that in the pools seldom over six feet except in the deeper sluggish area nearest the lake.

Dams

There are several dams on the main branches of the stream system within the experimental areas planted with salmon which prevent the ascent of fish. The only dam of importance in Duffin East is a grist mill dam in Section VII. Duffin West has three large dams within the experimental area located in Sections V and X. There are no dams within the experimental areas of any tributary streams. The remains of old dams are in evidence at many locations over the stream system.

Chemistry

Determinations of the pH of the water showed it to be slightly acidic over the stream system. In all areas planted with salmon the water was generally saturated with oxygen as a result of the steady flow and numerous riffles.

Pollution occurred near the stream mouth where the effluent from industrial operations at Ajax entered the stream. This was a considerable distance downstream from the lowest limit of salmon planting.

PLANTING DATA

The fry used in the experiment were hatched from Atlantic Salmon (*Salmo salar*) eggs of Miramichi stock and reared at the Glenora Fish Hatchery of the Provincial Government. When the fry had lost their yolk sacs and had been

feeding for about two weeks, they were planted in the stream. The fish had then reached an age of six weeks or more, and had attained a length of 2.5–3.0 cm.

The fry were transported by truck from the hatchery to Duffin Creek in ice-cooled containers. At the stream the fry were placed in portable retainer cages, located conveniently in the stream. Each cage had a volume of 22.5 cubic feet and consisted of a wooden frame supporting fine copper screening which allowed a circulation of fresh water within the cage. To facilitate planting, the retainer cages were moved to the areas to be planted each day, and from these cages the salmon were distributed along the immediate stream by use of screened milk pails.

During June of each year from 1945 to 1947, plantings of salmon fry were made over some 35,000 yards of Duffin Creek which offered a wide variety in

TABLE I. Numbers of salmon fry distributed in general plantings, 1945-47, inclusive.

Location	Yards planted each year	Number planted each year	Number per yard
Duffin East			
IV	500	500	1.0
V	1,000	1,000	1.0
VI	2,280	2,200	1.0
VII	880	800	0.9
VIII	2,380	2,500	1.1
IX	2,850	3,000	1.1
Duffin West			
IV	2,200	2,000	0.9
V	3,960	5,000	1.3
VI	1,500	1,500	1.0
VII	3,500	3,500	1.0
VIII	2,200	2,000	0.9
IX	2,280	2,000	0.9
X-A	750	750	1.0
X-B	500	500	1.0
Duffin East 1	500	500	1.0
Duffin East 2			
a	500	500	1.0
b	1,000	1,000	1.0
c	500	500	1.0
Duffin East 3			
a	500	500	1.0
b	1,000	1,000	1.0
c	750	750	1.0
d	250	250	1.0
Duffin East 4	500	500	1.0
Duffin East 5			
a	500	500	1.0
b	500	500	1.0
Duffin West 1	500	500	1.0
Duffin West 2	1,000	1,000	1.0
Total	34,780	35,250	1.0

stream conditions under which the survival and distribution of the planted fry could be studied. These plantings were made at a density of about one fry per yard of stream with no respect to local variations in stream conditions. Through repitition of the same planting procedure each year, it was possible to establish soundly the comparative survival under a wide range of habitat conditions. The data for these plantings are presented in Table I. Other plantings were made in 1944 and 1948 but were not studied in great detail except in limited areas.

POPULATION ASSESSMENT

A number of methods were employed to determine the survival and distribution of salmon parr resulting from each planting. These methods included the use of various types of nets and seines, fish traps, angling, creel census, tagging and direct observation. Although each method was of advantage in determining salmon abundance, it was necessary to adopt a standard method for population assessment in order that a comparison of the populations of salmon in different sections of the stream system could be made.

Following a consideration of available methods for determining fish numbers in streams, the "one-man" hand seine, as developed by H. C. White and others in work on Maritime streams, was adopted as offering certain advantages for this survival study, namely, that stream areas could be quickly and economically seined by one man, the fish examined, and returned immediately to the stream without injury. Further, the seining results readily revealed relative survivals of salmon under local habitat conditions over all parts of the stream system. On the basis of the seining results a rough estimate of stream populations could be made through a knowledge of this method.

Determinations of the efficiency of the operation of this seine, which consisted of four square feet of fine netting supported laterally by two stakes, were conducted in selected stream areas screened at each end to prevent movement of fish to or from the sections. Although several procedures were employed, the one adopted as a basis for population assessment required that the area be seined and that the captured salmon be recorded, marked by fin clipping, and returned to the stream. The area was again seined, the number of marked and unmarked fish recorded, unmarked fish marked, and all fish returned to the water. This procedure was repeated until no unmarked fish were captured in three consecutive seinings of the area.

As population studies were made only in the late summer and autumn, seining efficiency studies were made at that time. Preliminary studies suggested that light intensity, and also those factors influenced by freshet conditions, modified the efficiency of seining to a considerable extent.

The effect of light intensity on seining efficiency was clearly indicated. From the seinings of screened study areas on clear and cloudy days it was evident that greater numbers of salmon were captured on cloudy days or during evening hours than on bright sunny days. Furthermore, seining results under high light intensity showed a greater variation in efficiency. A study of the effects

of freshet conditions on seining efficiency clearly showed that the efficiency dropped to a low level as turbidity and volume of flow increased.

In order to overcome as much as possible the variable effect of these factors on the efficiency of the seining method, all seinings used to assess salmon numbers were carried out under more or less standard conditions. Seinings used for population assessment were made on overcast days, during early mornings or evenings rather than during periods of high light intensity. Further, they were made under normal stream conditions rather than during periods of freshet.

As age determinations showed the young salmon resident in the stream during the summer months to be either fish planted earlier in the same spring or fish planted the previous spring, the two age groups may be designated as "underyearling" and "yearling" salmon. A very few parr were found with an additional year of stream life.

Seining efficiency experiments, as outlined previously, were conducted in representative areas of the main and tributary streams. From this work it was found that the efficiency of the seining method generally lay within the range of 25 to 40 per cent of the total population for one seining of an area. As the average figures approximated 33 per cent, a reasonable estimate of stream populations of salmon parr could be made by multiplying threefold the number of salmon captured in one seining of an area. For both underyearling and yearling fish it would seem that the efficiency was slightly higher in the upper parts of the main and tributary streams than farther downstream. Further, the seining efficiency factor of 3 tended to underestimate the number of yearling and overestimate the number of underyearling parr. Regardless of these limitations, once a satisfactory technique had been developed in operating the small seine, the results obtained formed as reliable a basis for population estimates as other established non-lethal methods. In addition it had those advantages pertinent to this study as outlined previously.

During the three-year period from 1945 to 1947, the planted areas of the stream system were seined at least twice each year in order to obtain a comparative picture of the salmon which survived from each planting, and their distribution. The number of salmon present in the autumn of each was then estimated from the results of the later seining. These figures showed very clearly the pattern of survival and distribution as outlined in the following section.

SURVIVAL AND DISTRIBUTION OF SALMON

Underyearling Populations

For a period of two or more weeks following each planting of fry, the small fish could be seined and frequently observed in the shallow gravelly riffles and in the shallow areas along the stream banks.

The fish gradually moved more into the riffle areas with a current sufficiently turbulent to hide them from view. They then remained in these riffle areas for some weeks. By late summer, the underyearling parr were found in gravel and rubble riffle areas with a moderate flow, in locations with low overhanging banks

or vegetation, and adjacent to fallen logs, roots and boulders when in pools. The local habitat of the underyearling parr will be described in detail in an analysis of factors affecting their survival.

The estimated August-September populations of underyearling salmon in each experimental area resulting from each of the three general plantings are presented in Table II. As a comparison of populations from area to area is of

TABLE II. Estimated autumn survival of underyearling salmon.

Location	Estimated population				Estimated population as percentage of number planted			
	Year of planting				Year of planting			
	1945	1946	1947	Average	1945	1946	1947	Average
Duffin East IV	0	0	0	0	0.0	0.0	0.0	0.0
V	60	27	81	56	6.0	2.7	8.1	5.6
VI	273	279	372	308	12.4	12.7	16.9	14.0
VII	498	435	498	477	19.9	17.4	19.9	19.1
VIII	159	102	177	146	19.9	12.8	22.1	18.3
IX	714	942	942	866	23.8	31.4	31.4	28.9
Total	1,704	1,785	2,070	1,853	17.0	17.9	20.7	18.5
Duffin West IV	0	0	0	0	0.0	0.0	0.0	0.0
V	0	0	0	0	0.0	0.0	0.0	0.0
VI	0	0	0	0	0.0	0.0	0.0	0.0
VII	210	105	210	175	6.5	3.0	6.0	5.2
VIII	264	132	462	286	13.2	6.6	23.1	14.3
IX	273	342	615	410	13.7	17.1	30.8	20.5
X-A	243	144	234	207	31.2	19.2	31.3	27.2
X-B	30	72	24	42	6.0	14.4	4.8	8.4
Total	1,020	795	1,545	1,120	5.9	4.6	9.0	6.5
Duffin East 1	0	0	0	0	0.0	0.0	0.0	0.0
Duffin East 2a	18	9	6	11	3.6	1.8	1.2	2.2
b	660	240	570	490	66.0	24.0	57.0	49.0
c	150	93	108	117	30.0	18.6	21.6	23.4
Total	828	342	684	618	41.4	17.1	34.2	30.9
Duffin East 3a	0	15	0	5	0.0	3.0	0.0	1.0
b	270	426	183	293	27.0	42.6	18.3	29.3
c	159	87	87	111	21.2	11.6	11.6	14.8
d	27	33	63	41	10.7	13.2	12.6	12.2
Total	456	561	333	450	18.2	22.4	13.3	18.0
Duffin East 4	0	0	0	0	0.0	0.0	0.0	0.0
Duffin East 5a	75	30	60	55	15.0	6.0	12.0	11.0
b	186	78	222	162	37.2	17.6	44.4	33.1
Total	261	108	282	217	26.1	10.8	28.2	21.7
Duffin West 1	0	0	0	0	0.0	0.0	0.0	0.0
Duffin West 2	210	150	216	192	21.0	15.0	21.6	19.2
Grand total for the creek system	4,479	3,741	5,130	4,450	12.8	10.7	14.6	12.7

little value unless the number of salmon planted is considered, the estimated populations are presented as a percentage of the number planted, that is, as percentage survival.

From this table of underyearling salmon survivals, certain significant facts became apparent. The estimated autumn populations of 4,479, 3,741, and 5,130 salmon resulting from the plantings of 1945, 1946 and 1947, respectively, represent a mean percentage survival of 12 per cent from time of planting in June until August-September for the entire length of stream planted with fry. There was a great variety in survival from one section of the stream to another. Whereas certain sections were marked by a total disappearance of salmon, survivals in other sections reached as high as 49 per cent.

The striking similarity in survivals within the different stream areas from year to year produced a general pattern of survival resulting from each planting which may be described as follows: Over Duffin East there was a general increase in percentage survival in each experimental area from the lower to the upper limit of planting with an increase from no survival in section IV to an average survival of 28.9 per cent in section IX for the three plantings. Over Duffin West the average underyearling percentage survival increased from zero in the lower sections IV, V and VI to 27.2 in section X-A, above which, in section X-B, there was a sharp decrease with an average survival of 10.2 per cent. In each area of Duffin West there was generally a greater variation in percentage survival from year to year than in Duffin East.

In those tributary streams which supported an autumn underyearling population, namely, Duffin East 2, 3 and 5, and Duffin West 2, a considerable variation in underyearling salmon survival was exhibited in different years. However, the general pattern of survival, as shown by an average of the results of the three plantings, was similar. Duffin East 2 showed a very low percentage survival in the section nearest the mouth, averaging 2.2 per cent over the three-year period; the mid-section, averaging 49.0 per cent, had the highest survival. The average survival figure then dropped to 23.4 per cent in the upper sections. In Duffin East 3, no population of salmon was found following two of the three plantings, giving a mean survival of 1.0 per cent for the three years. The mid-section then exhibited the highest average three-year survival of 29.3 per cent, which decreased to 12.2 per cent in the upper section. Duffin East 5 had an average survival of 33.1 per cent in the upper section but only 11.0 near the mouth. Duffin West 2 showed a relatively constant underyearling autumn survival each year which averaged 19.2 per cent.

Yearling Populations

Yearling salmon were characteristically captured in riffles, deep pools, beneath undercut banks and overhanging vegetation, and around boulders, logs and other obstacles on the stream bottom. Further description of the yearling salmon habitat will be given later in this paper.

Table III records the estimated autumn yearling populations of those salmon planted as fry in the three general plantings. By the end of the second summer

after planting the average survival was 9.2 per cent of the number planted, varying from 8.2 per cent in 1946 to 9.7 per cent in 1947.

TABLE III. Estimated autumn survival of yearling salmon.

Location	Estimated population				Estimated population as percentage of number planted			
	Year of planting				Year of planting			
	1945	1946	1947	Average	1945	1946	1947	Average
Duffin East IV	0	0	0	0	0.0	0.0	0.0	0.0
V	87	60	93	80	8.7	6.0	9.3	8.0
VI	219	276	297	264	10.0	12.5	9.8	10.8
VII	156	105	162	141	19.5	12.6	20.3	17.5
VIII	429	471	456	452	17.3	18.8	18.6	18.2
IX	768	684	822	758	25.6	22.8	27.4	25.3
Total	1,659	1,596	1,830	1,695	16.6	16.0	18.5	17.0
Duffin West IV	0	0	...	0	0.0	0.0	...	0.0
V	0	0	...	0	0.0	0.0	...	0.0
VI	0	0	...	0	0.0	0.0	...	0.0
VII	315	102	...	209	9.0	2.9	...	6.0
VIII	210	207	...	208	10.5	10.4	...	10.4
IX	204	273	...	237	10.2	13.7	...	12.0
X-A	144	126	...	135	18.7	16.8	...	18.0
X-B	0	27	...	15	0.0	5.4	...	2.7
Total	873	735	...	804	5.1	4.3	...	4.7
Duffin East 1	0	0	0	0	0.0	0.0	0.0	0.0
Duffin East 2a	9	12	9	10	1.8	0.0	1.8	1.2
b	339	120	183	214	33.9	12.0	18.3	21.4
c	30	48	90	56	6.0	9.6	18.0	11.2
Total	378	180	282	280	18.9	9.0	14.1	14.0
Duffin East 3a	45	0	0	15	9.0	0.0	0.0	3.0
b	150	117	132	133	15.0	11.7	13.2	13.3
c	48	24	42	38	6.4	3.2	5.6	5.1
d	9	18	24	17	3.6	7.2	4.8	5.2
Total	252	159	198	203	10.1	6.4	7.9	8.1
Duffin East 4	0	0	0	0	0.0	0.0	0.0	0.0
Duffin East 5a	33	48	36	39	6.6	9.6	7.2	7.8
b	45	60	78	61	9.0	12.0	15.6	12.2
Total	78	108	114	100	7.8	10.8	11.4	10.0
Duffin West 1	0	0	0	0	0.0	0.0	0.0	0.0
Duffin West 2	153	123	189	155	15.3	12.3	18.9	15.5
Grand total for the creek system	3,393	2,901	3,417	3,237	9.6	8.2	9.7	9.2

Population studies showed that certain experimental areas, namely Duffin East IV, Duffin West IV, V and VI, Duffin East 1 and 4, and Duffin West 1 supported no population of yearling salmon. Also apparent was the fact that the

same general pattern of survival over the stream system resulted from each planting.

Over Duffin East the percentage survival of the planted salmon at the end of the second autumn showed a general increase from no survival in section IV to 25.3 per cent in section IX. Over Duffin West the average yearling survival increased from zero per cent in sections IV, V and VI to 18 per cent in X-A above which there was a sharp decrease to an average survival of only 2.4 per cent.

Those tributary streams which supported an autumn yearling population were Duffin East 2, 3 and 5, and Duffin West 1. Although a marked variation in the survival of yearling salmon was exhibited in the tributary streams from year to year, the general pattern, as illustrated by an average of the results of the three plantings, was similar for all plantings.

Comparison of Yearling and Underyearling Populations

The results of the three general plantings have been presented as the estimated survival until the autumn of the first year (as underyearlings) and until the autumn of the second year (as yearlings). From a comparison of the estimated autumn underyearling and yearling populations in the different sections of the stream system it is seen that considerable movement as well as some mortality must have occurred during the intervening year. The average number of yearlings was found to be 70.7 per cent of the underyearling population with a variation from 160 per cent in Duffin East V to 35.4 per cent in Duffin East 3c. Percentage survivals exceeding 80 per cent of the underyearling population were characteristic of both main branches, and the tributary Duffin West 2. Lower survivals were found in the other tributary streams.

Comparison of underyearling and yearling survivals shows that the greatest mortality of salmon occurred between the time of planting and the autumn of the first year. Mortality between the autumn of the first year and the autumn of the second year was relatively low.

Movement of Parr

Observations on the movement of parr within planted sections was limited to a study of only 52 underyearling salmon marked by clipping the adipose and pectoral fins, since it was desirable to handle the planted fish as little as possible. Movements of fish into unplanted areas were also noted although these areas were too extensive to allow detailed study. For this reason only the more likely salmon habitats were seined in detail.

The recorded occurrences of salmon in unplanted areas are presented in Table IV. The number of *underyearling* salmon which moved into unplanted areas was small, although both upstream and downstream movements were recorded. Streams with a recorded movement into unplanted areas were Duffin East, Duffin East 2, and Duffin West 2. No upstream movements greater than 15 yards beyond the upper limit of planting were recorded. However, underyearling salmon were found to have moved downstream at least 700 yards in

TABLE IV. Occurrence of salmon parr in unplanted creek sections.

Year of planting	Section of capture	Number captured	Month of capture	Direction of movement	Remarks
Underyearling					
1945	Duffin East VIIa	4	August	downstream	minimum movement of 700 yds. downstream
1945	Duffin West 2a	2	September	downstream	captured within 300 yards of section planted
1945	Duffin West 2c	1	August	upstream	captured 10 yds. above upper limit of planting
1946	Duffin East VIIa	5	August	downstream	captured within 200 yds. of lower planting limit in section Duffin East VIII
1947	Duffin East VIIa	2	July	downstream	captured within 50 yds. of lower limit of planting in section VIII
1947	Duffin West 2a	1	August	downstream	captured 20 yds. below limit of planting
1948	Duffin East 3d	2	October	upstream	captured within 15 yds. of upper planting limit
1948	Duffin East VIIa	3	September	downstream	captured within 30 yards of lower planting limit of Duffin East VIII
Yearling					
1945	Duffin East X	3	July	upstream	captured within 500 yds. of upper planting limit
1945	Duffin East X	2	August	upstream	captured within 200 yds. of upper planting limit
1945	Duffin West 2	3	August	upstream	captured within 400 yds. of upper planting limit
1945	Duffin East 3c	1	September	upstream	captured about 25 yds. from upper planting limit
1945	Duffin West 2b	2	August	downstream	captured within 200 yds. of lower planting limit
1946	Duffin East X	1	August	upstream	captured 500 yds. above upper planting limit
1946	Duffin East 3	1	August	upstream	captured about 25 yds. from upper limit of planting
1947	Duffin West 2	1	August	upstream	captured about 200 yds. from upper planting limit
1947	Duffin West 2a	1	August	downstream	captured 50 yds. below limit of planting
1947	Duffin East X	2	September	upstream	captured within 100 yards of upper limit of planting

Duffin East during 1945. In the other streams the recorded downstream movement was somewhat less.

Among *yearling* salmon there was both an upstream and downstream movement into unplanted areas. The greatest downstream movement into unplanted areas was observed in Duffin East where three salmon were found 200 yards below the lower limit of planting. The maximum upstream shift of a yearling salmon was about 500 yards, recorded in Duffin East for one of the 1946 planting. One two-year-old salmon of the 1945 planting was captured in Duffin East in 1947 at a distance of some 2,200 yards upstream from the upper limit of planting.

During the autumn of 1947, 27 underyearling salmon were marked in Duffin East 2b by clipping fins; also, 25 underyearlings were marked in Duffin East 3b by clipping the adipose fin. Some 19.2 per cent of these marked fish were again captured the following year, Table V. Of the 27 underyearlings in Duffin East 2b, three were recaptured the following year at points lower down in the stream, one in Duffin East slightly above the entrance of Duffin East 2, and one in the area where marked. Recoveries from the 25 underyearlings in Duffin East 3b were: one in Duffin East VIII below the entrance of Duffin East 3, and two in the area where marked.

TABLE V. The recapture of salmon parr marked during 1947.

Creek section where marked	Number marked	Creek where captured	Number recaptured	Remarks
Duffin East 3b	27	Duffin East 3	3	Parr recaptured as yearlings to a distance of about 1,000 yards downstream.
		Duffin East IX	1	Parr recaptured as yearling in main creek about 100 yards from mouth of Duffin East 3, a downstream movement of about 1,600 yards
		Duffin East 3	1	Parr recaptured as yearling in section where marked
Duffin East 5b	25	Duffin East 5	2	Parr recaptured as yearlings about 400 yards below where marked
		Duffin East VIII	1	Parr recaptured as yearling in main creek below entrance of this tributary, a movement of about 1,500 yards
		Duffin East 5	2	Parr recaptured as yearling in section where marked

In summary, there was a downward movement of salmon from the tributary streams to the main stream between the autumn of the first year and the following summer. Further, only a small percentage of the fish marked in the tributary streams as underyearlings were still present in the same areas as yearlings. These observations are consistent with the lower apparent survival rate in the tributary streams.

DESCENT OF SMOLTS

During the spring of 1948 a count of descending smolts was made with a fish trap at the Greenwood dam in section VII of Duffin East, and a trap net located near the stream mouth in section II.

The fish trap in the Greenwood dam was not in operation until May 2, by which time a large proportion of the smolts had descended. No smolts were captured after May 13. During this period, with mean water temperatures ranging from 50° to 60°C., only 32 smolts were captured.

However, the trap net set near the stream mouth was in continuous operation from April 15, the first date at which ice and flooding conditions permitted installation, until June 21, except for several days during which extreme flood conditions prevailed. Mean water temperatures ranged from 47° to 74° during this period.

During the period of operation some 556 smolts were captured in the trap net. This included 146 in April, 406 in May, and 4 in June. As three smolts were captured on the first day of operation, it is probable that smolts had descended previously. By scale reading it was found that some 98 per cent of the descending smolts were the result of the 1946 planting.

In order to determine the efficiency of the trap net, two additional nets were placed in series downstream. As a result of this study it was concluded that roughly 66 per cent of the descending smolts were captured in the permanent net. In consideration of the efficiency of the equipment and the time during which it was not in operation, it would seem that no greater than 50 per cent of the descending smolts could have been captured. Assuming that 50 per cent were captured, the number of smolts which passed through the netting location may be estimated at about 1,100, or about 3 per cent of the fry planted in 1946.

Although no record of smolt descent was obtained in other years, the similarity of the estimated yearling salmon populations of each planting would suggest that a similar number of smolts would descend as a result of the plantings of 1945 and 1947.

All smolts captured in the nets during 1948 were marked by clipping the adipose fin and returned to the stream immediately below the nets.

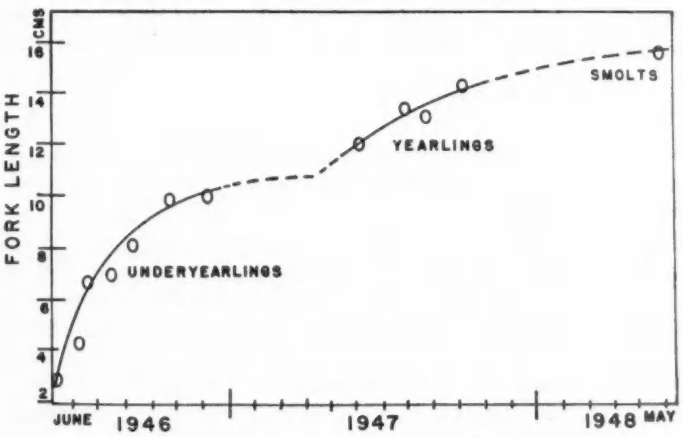

FIGURE 2. Average growth of salmon planted as fry in 1946.

AGE AND GROWTH OF PARR AND SMOLTS

Salmon parr captured in Duffin Creek, as shown by a study of the scales, were nearly all underyearling and yearling fish. The parr remained in the stream until the spring of the second year following planting when nearly all descended to the lake as smolts. Only very few parr remained in the stream for an additional year. Of the 556 descending smolts captured at the stream mouth in the spring of 1948, 3 were of age I, 18 of age III, and the remainder of age II.

Measurements of the fork lengths of a large number of the salmon captured each year were made. These data showed the lengths of similarly aged parr to vary slightly from section to section. Although there was apparently a slightly higher growth rate for the salmon in the warmer waters than for those in the cooler waters, the variation in growth was not great. The average growth of the salmon planted in 1946 is presented in Figure 2.

The Duffin Creek salmon grew similarly to those in Maritime streams. The 556 smolts captured near the mouth of Duffin Creek in 1948 had an average length of 15.4 (10.4–19.8) cm.

II. Factors Affecting Survival

Part I shows that a common pattern of survival of underyearling and yearling parr resulted from the three general plantings of 1945, 1946 and 1947, when salmon fry were distributed over a large part of the stream system at a density of one fry per yard of stream. The great similarity in results allows an analysis of the factors which may cause the disappearance of salmon from certain sections, and permit their survival in others.

There was a total disappearance of salmon from the lowest planted section of Duffin East (section IV), the lower parts of Duffin West (sections IV, V and VI), and the tributary streams Duffin East 1, Duffin East 4 and Duffin West 1 (Tables II, III). Also, the survival in both Duffin East and Duffin West generally increased as the streams were ascended from the lower to the upper sections, excepting section X-B of Duffin West. The tributary streams exhibited better survivals in their upper and intermediate sections than near their mouths.

TEMPERATURE

Creek Conditions

From 1945 to 1948 water temperatures were recorded over the creek system whenever each section was visited for any purpose. This gave a general picture of summer temperatures.

During each year stream temperature surveys were made to determine maximum temperatures at selected locations on the warmest summer days. Maximum-minimum temperature curves were also obtained in selected locations by recording the temperature periodically during periods of high temperature.

During the summer of 1947 a daily record of maximum-minimum temperatures was made in sections VI of Duffin East and Duffin West, points roughly equidistant from source and mouth of each branch, in order to compare temperatures in the two branches.

The maximum water temperatures recorded during the summer months from 1945 to 1948 at selected locations over the creek system are presented in Table VI. The pattern of maximum temperatures was identical each year, although the actual temperatures varied by several degrees. The average maximum temperature in Duffin East increased from 21.0°C. in section IX to 30.6° in section III, and in Duffin West from 25.7° to 32.8°, in similar locations. The maximum temperatures in sections III, VI and IX of each branch show a higher temperature at each location in Duffin West than in Duffin East. The spring source streams of either branch failed to rise above 13.5°.

The maximum temperatures at specific locations in the tributary streams varied little from year to year, with a general increase from source to mouth of each stream.

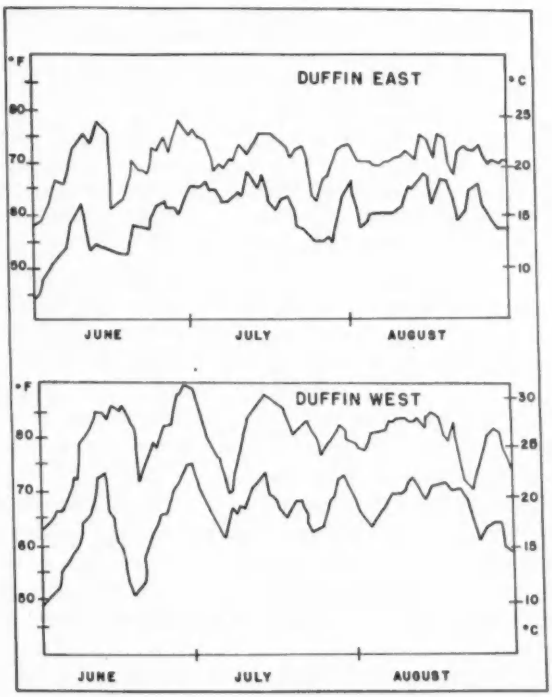

FIGURE 3. Maximum and minimum water temperatures at Section VI of Duffin East and Duffin West, during the summer of 1947.

The daily record of maximum and minimum temperatures in sections VI of Duffin East and Duffin West during the summer of 1947 is shown in Figure 3. From a comparison of the two curves it is seen that the daily fluctuations in maximum and minimum temperatures were greater in Duffin West than in Duffin East, that the range between daily maximum and minimum was also

greater in Duffin West, and the temperatures reached considerably higher maxima in Duffin West, than in Duffin East. The average mean temperature for the three-month period for Duffin East was 19.4°C., and for Duffin West was 22.7°C.

These general observations on stream temperatures illustrate the principles that the maximum water temperature increases from source to mouth, and that the higher the maximum temperature, the greater is the fluctuation in water temperatures during each day, and from day to day.

TABLE VI. Maximum observed creek water temperatures.

Location	Temperature, degrees C.				
	1945	1946	1947	1948	Average
Duffin East III	30.0	29.4	31.8	13.2	26.1
VI	23.6	24.9	25.7	24.5	24.7
IX	20.1	21.0	21.8	21.6	21.0
Duffin West III	32.7	33.1	33.8	31.6	32.8
VI	29.6	30.5	32.5	29.8	30.6
IX	24.3	25.3	27.5	25.8	25.7
Duffin East 1	33.3	33.7	35.4	33.0	33.9
Duffin East 2a	21.9	21.7	22.9	21.3	22.0
c	20.8	19.5	20.4	18.9	19.9
Duffin East 3a	29.4	28.8	30.6	29.5	29.6
c	20.6	21.2	23.2	22.1	21.8
Duffin East 4	32.6	34.3	31.5	32.2	32.7
Duffin East 5a	21.2	24.4	20.4	22.2	21.1
c	15.2	15.7	15.5	15.4	15.5
Duffin West 1	31.0	35.3	34.2	32.9	33.4
Duffin West 2	24.3	24.5	25.9	23.7	24.6

EFFECT ON SALMON SURVIVAL

It was indicated early in the investigation that lethal temperatures probably caused the total absence of parr in those stream areas with no August-September populations. The results of seinings in these areas revealed that some of the planted fry survived and developed normally until their sudden disappearance. The factor which destroyed the population was, therefore, present at certain times and acted quickly.

This general observation led to a study of the survival and subsequent disappearance of the planted fry in Duffin West V during the summer of 1945. The recorded water temperatures and seining results in this area are given in Table VII.

Parr were present on June 17 and showed normal growth, but on and after June 25, no parr could be captured. A study of stream conditions during this period showed no appreciable environmental change other than a large increase in water temperature to a maximum of 30.5°C. Fry (1947b) has given the upper incipient lethal temperature for the salmon as 28.5°. Thus, in the period during

TABLE VII. Water temperatures and seining results in section V, Duffin West, 1946.

Date	Water temperature		Length of area seined	No. of fry seined	Average length
	Maximum	Minimum			
	°C.	°C.	*yards*		*cm.*
June 11	17.5	12.5	50	2	3.6
15	20.0	12.0			
17	18.0	11.0	200	6	4.3
19	17.5	13.0			
20	21.0	16.5			
21	24.0	21.0			
22	27.0	22.5			
23	29.0	22.5			
24	30.5	21.5			
25	28.5	22.0	500	0	...
26	30.0	21.5			
29–30	...	...	2,500	0	...
Aug. 28–9	...	...	2,500	0	...

which the salmon disappeared, the water reached a temperature sufficiently high to cause their death.

Further evidence of the lethal effect of temperature on the planted salmon was obtained during the planting of June 27, 1947. While planting fry in the lower part of Duffin West, the fry were observed to die within several hours after planting. The mortality of a number of salmon held in a retainer cage placed in the stream in Section V was also observed on the same date. On this date the water temperature at the hatchery was about 15.0°C. The stream water had a temperature of 14.5°C. at 9:00 a.m. but by 11:45 a.m. had reached 21.0°C. By 3:00 p.m. a temperature of 30.5°C. had been attained.

The fry were transferred from the hatchery truck (water temperature 16.5°C.) at about 11:00 a.m. Between 1:00 and 3:00 p.m. a number of dead parr was collected. After 3:00 p.m. no live parr could be found. As no other environmental condition was altered during this period, it would seem proper to conclude that the sudden rise in temperature caused the death of the salmon.

The above observations on the lethal effect of high water temperatures on the planted fry are substantiated by experimental work done by Fry (1947b). This relation between temperature and time to death, for fingerling salmon acclimated to various temperatures, is presented in Figure 4.

The environmental temperature has been divided by Fry (1947a) into the following zones: (*a*) the zone of tolerance in which organisms can live indefinitely, (*b*) the upper and lower incipient lethal levels demarcating the zone of tolerance, and (*c*) a zone beyond the zone of tolerance in which the organisms can live for only a short period of time. The limits of these zones are modified by the thermal experience of the organism.

A study of the effect of lethal water temperatures on the salmon must, therefore, consider three points: (*a*) the thermal history on which the lethal temperature limits are dependent, (*b*) the incipient lethal level, that temperature

beyond which the organism cannot live for an indefinite period of time, and (*c*) the resistance time, the length of time that the organism can resist the effects of the lethal temperature.

It was shown previously that the water temperatures in Duffin West VI during the planting of June 27, 1947, were lethal to the salmon fry. This may be explained through the work of Fry (1947b) as given in Figure 4. The acclimation temperature of the fry at the hatchery was approximately 15°C. which would set the upper incipient lethal temperature for the fish at not over 27.0°. Following the planting, the stream temperature rose to 30.5° within four hours. This field observation is what would be predicated from the theoretical curve.

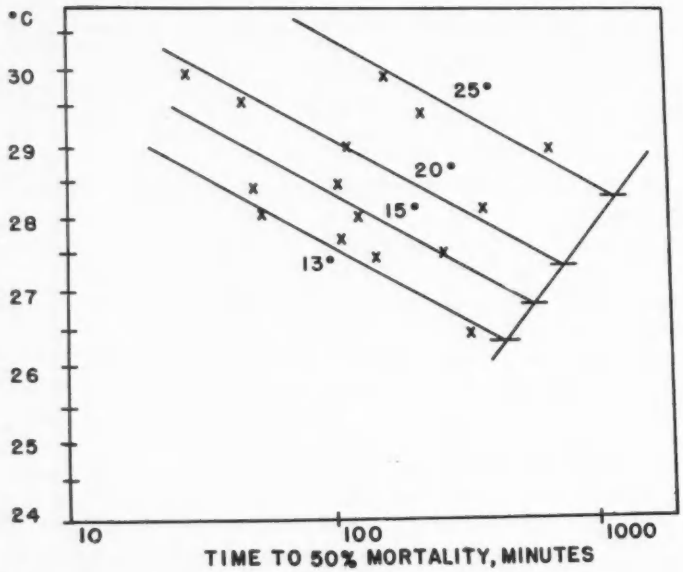

FIGURE 4. Relation between temperature and time to death for fingerling salmon acclimated to various temperatures, from Fry (1947b).

Experimental laboratory studies on the temperature-activity relation of the salmon, to be outlined later, determined that the upper incipient lethal temperature for young salmon was 28.5° at an acclimation of 25.0° or higher. In those streams with high maximum temperatures, the wide fluctuation in daily maximum and minimum temperatures tends to keep the acclimation temperature at a lower level than might be expected. In those streams which do not have maximum temperatures above the lethal level, the acclimation temperature for salmon would not reach 25°.

From the record of maximum summer temperatures at locations over the creek system, presented in Table VIII, it was shown that certain stream sections had summer temperatures sufficiently high to cause the death of any resident

salmon. In these sections, namely Duffin West IV, V, VI, Duffin East IV, and tributary streams of Duffin East 1 and 4, and Duffin West 1, no underyearling or yearling populations could be found during the summer months.

As a result of stream and laboratory observations, it may be concluded that the total disappearance of planted salmon from certain stream sections was caused by lethal summer water temperatures.

A consideration of sub-lethal water temperatures has led to the conclusion that they do not directly cause the pattern of survival which characterized the planted sections of Duffin Creek. It may be seen from preceding data that high and low percentage survivals were found in both warm and cool streams. For example, a high survival of salmon was characteristic of a cool stream, Duffin East 5b (maximum of 15.5°C.), and a warm stream, Duffin West 2 (maximum of 24.4°).

Although a comparison of percentage survival and maximum summer temperature in the planted sections showed an inverse correlation of these conditions in both Duffin East and Duffin West, marked local variations in survivals within each stream section indicates clearly that a factor other than temperature was operating to produce the common pattern of survival which resulted from each planting.

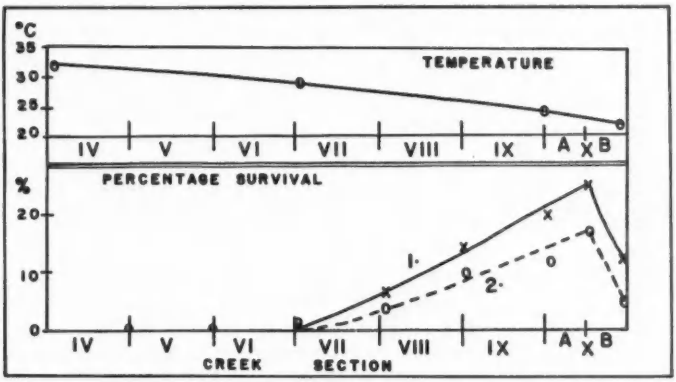

FIGURE 5. A comparison of maximum water temperatures and salmon survival in Duffin West: (1) Underyearling salmon; (2) Yearling salmon.

The relation of maximum temperatures and survival of salmon in Duffin West is shown in Figure 5. There is an absence of salmon below the sections characterized by lethal temperatures. Above the section of lethal temperature, the percentage survival of salmon increased as the maximum temperature decreased. However, this inverse correlation ceased in section X, where the percentage survival dropped abruptly.

In conclusion, it may be stated that lethal summer water temperatures destroyed salmon populations in certain stream sections, but that sub-lethal temperatures had no significant effect on either survival or distribution of the fish.

TURBIDITY

Creek Conditions

Measurements of water turbidities were made by means of a small portable instrument by which the transmission of light through a water sample was measured by a photometer calibrated to express standard turbidity units.

Measurements were made at a series of stations over the creek system during the years of 1947 and 1948. The stations were located in section II of the main stream, sections III, VI and IX of Duffin East and Duffin West, and in the tributary streams. Measurements were made at these stations under normal water conditions, and during the following periods of rain.

The water turbidities recorded under normal conditions are presented in the left part of Table VIII.

Table VIII. Normal and maximum observed water turbidities in Duffin Creek, 1947–48

Creek section	Turbidity units		
	Normal conditions	Maximum conditions	Ratio of maximum to normal
Duffin Creek II	37	1,920	52
Duffin East III	30	1,500	50
VI	9	265	29
IX	4	65	16
Duffin West III	47	1,780	38
VI	15	750	50
IX	12	220	18
Duffin East 2a	12	175	15
c	3	135	45
Duffin East 4a	20	440	22
c	6	160	27
Duffin East 5a	12	240	20
b	3	38	13
Duffin West 2b	6	185	31

The turbidity of the water of the main branches, Duffin East and Duffin West, increased as the stream was descended from source to mouth. In descending some 12,000 yards from section IX to section III of Duffin East, the turbidity of the water increased about eightfold. Over the corresponding length of Duffin West, the increase in turbidity was roughly four times. However, the water of Duffin West showed a much greater turbidity than that of Duffin East at similar locations. Over the relatively short lengths of the tributary streams, the turbidity increased considerably from source to mouth.

The maximum observed water turbidities caused by freshet conditions, as recorded at the observation stations, are presented in Table VIII. Under freshet conditions turbidities show a marked increase over normal conditions. For example, in section II near the stream mouth the increase in turbidity was some 52 times.

Additional measurements of turbidity were made during and following a typical summer rain of 5.4 hours' duration. This study of the effect of precipitation on water turbidities was carried out in sections III, VI and IX of Duffin East during August of 1947. Measurements were made previous to the start of rain, at two-hour intervals during rain, and again 12 and 24 hours after its cessation (Figure 6.)

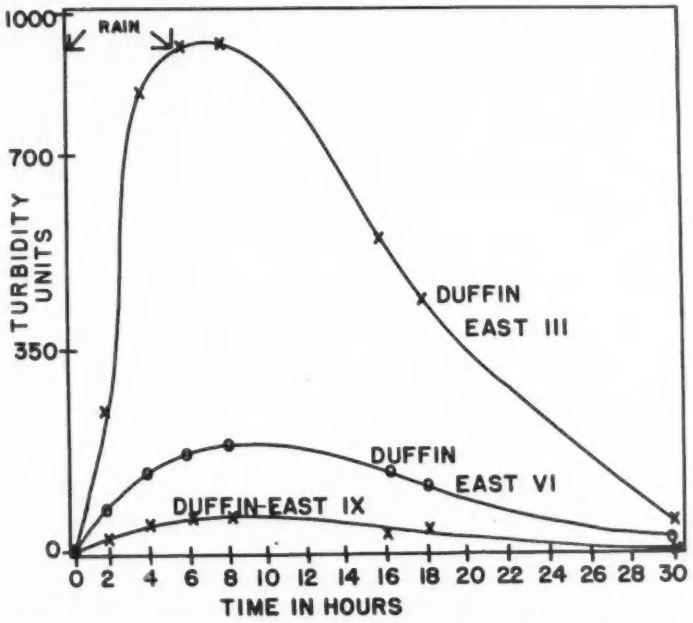

FIGURE 6. Observed turbidities at three locations in Duffin East during and following a summer rain of 5.4 hours duration.

There was a characteristic turbidity curve for each of these locations. The increase in turbidity was least in the section nearest the source, and greatest in the section nearest the mouth. In each location the turbidity continued to rise after the rain ceased. Measurements made 12 hours after end of the rain showed that in sections VI and IX the turbidity of the water had returned to nearly normal. By 24 hours after, the water in section III had not yet returned to its normal degree of turbidity.

In summary, under normal stream conditions there was an increase in turbidity from source to mouth of each stream. Under freshet conditions there was a large increase in turbidity in all parts of the stream system. As each stream descended from source to mouth, the rate of increase in turbidity caused by freshet conditions became greater, the maximum turbidity generally became greater, and the time required for the turbidity to return from the maximum to normal was increased.

Effect on Salmon Survival

It has been shown that there was an increase in the turbidity of the water of each stream from source to mouth, particularly evident in the main streams, Duffin East and Duffin West. Conversely, the percentage survival of the salmon parr decreased generally from the upper to the lower limits of planting. This relationship has been presented graphically for Duffin West in Figure 7.

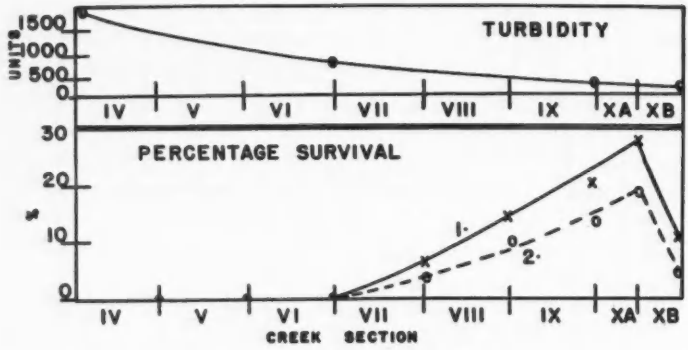

Figure 7. A comparison of normal water turbidity and salmon survival in Duffin West: (1) Underyearling salmon; (2) Yearling salmon.

In order to determine the possible effect of water turbidity on the survival and distribution of the planted salmon, field and laboratory studies were undertaken.

Several studies of the effect of high stream turbidities on the salmon were carried out by placing parr in retainer cages at various locations during periods of freshets. During October of 1947, 25 underyearling parr were retained in section IV of Duffin East, some distance below the lower limit of planting. Autumn freshets during this period caused turbidities in excess of 1,150 units. As only four of the parr died during the two-week period, it may be concluded that this degree of turbidity was not lethal to the fish. The death of the four fish was attributed to the current forcing them against the lower end of the cage, a condition frequently observed. It must be noted that this turbidity of 1,150 units was greater than any found in sections V and VI from which there was a total disappearance of salmon each year.

Further evidence of the survival of salmon under relatively high turbidities was gained during the summer of 1948 when 3,000 underyearling salmon were held with low mortality in a small tributary stream. Turbidities in excess of 800 units were recorded periodically. This degree of turbidity exceeded maximum turbidities in the tributary stream, Duffin East 4, in which no planted salmon survived.

From these evidences of the survival of small salmon under conditions of

high turbidity, it may be concluded that the effect of the maximum water turbidity in any of the areas planted with salmon was not such as to cause apparent injury, or death, to the fish.

An increase in turbidity must cause a reduction in visibility on the part of the salmon and other fish. It would seem probable then, that extremely turbid water would so reduce visibility that feeding of the fish would be curtailed. As extreme turbidities were of relatively short duration, the long period during which a fish can exist without feeding eliminated any possibility of starvation as a factor in salmon mortality.

If increases in water turbidity reduce visibility through the water, then turbid water should protect the small salmon from aquatic and other predators which depend upon sight to effect capture. Several observations of the use of turbid water as protective cover by small salmon were made. A yearling speckled trout was placed in a tank of clear water with five underyearling salmon. Two of the salmon were eaten by the trout in less than three minutes. Turbid water was run into the tank and no parr was captured during the following hour. Clear water was again run through the tank and the remaining parr were soon captured. This observation would indicate that the chance of capture by the trout was decreased by the presence of turbid water.

It was noted on numerous occasions when observing salmon parr in the streams that, when a bit of stream bottom was loosened to cause an area of turbid water, the salmon would generally move immediately into the turbid area and escape from view. After some time they would move back into clearer water, but on a sudden movement by the observer would dart back into the turbid zone.

As the water of the planted part of the Duffin Creek system has but a low turbidity under normal stream conditions, any possible effect of turbid water as a defence against predation would be limited to times of freshet. Hence the effect of turbidity cannot be considered an important factor in influencing the observed pattern of survival through the fry and parr stage. However, it should be noted that the descent of smolts to the lake each spring occurred at a time when turbidities were high. This turbid water at that time should tend to protect the descending fish from larger predators in the lower stream sections and river mouth.

As a result of observations concerning the effect of turbid water on the survival pattern of the planted salmon, the following conclusions may be drawn: (1) Water turbidities as occurring in the planted part of the creek system were not lethal to the salmon fry and parr. (2) There was no evidence that turbid water had any harmful effect on the salmon. (3) Turbid water may offer smolts protection from predation in descent to the lake during spring freshets.

PREDATION

The importance of predation on the survival of the salmon was studied through observations made in the field and laboratory. Those species found to be predators of the young salmon will be discussed in the following section.

Man

The importance of man as a predator may be considered insignificant in this particular study. This was the result of control measures on the anglers rather than on their inability to capture larger parr through angling.

Underyearling parr were seldom captured by angling with baits commonly used to take legal trout. However, yearling parr could be captured frequently by angling with flies and worms. For example, an accomplished fisherman leasing one-half mile in section VII of Duffin East reported taking over 100 yearling salmon by actual count while angling for speckled trout during 1947. As these fish were returned to the water unmarked, it is presumed that there were many recaptures.

Smolts could be captured infrequently by angling during their descent to the lake in the spring months. Although an uncommon occurrence, three anglers captured seven smolts at the Greenwood dam during May of 1947. Also, several smolts were taken in sucker dip nets at the river mouth although this was not a frequent happening.

From this evidence it may be concluded that underyearling salmon were more or less immune from capture by anglers, but that yearling salmon and descending smolts were potential prey for the angler's hook. However, adequate control of angling precluded a large enough catch to affect the pattern of survival which characterized the stream system.

Fish

EASTERN BROOK TROUT (*Salvelinus fontinalis*). The brook trout inhabits the cooler waters of Duffin Creek. It was rarely found in Duffin West below section IX, or in Duffin East below section VI. As the upper incipient lethal temperature for brook trout is lower than that for salmon, the former did not occur in those places where high temperature prohibited summer salmon populations.

The first evidence of the predation of brook trout on salmon was gained when several underyearling salmon (3.0–3.5 cm.) and a brook trout (12.8 cm.) were placed in a retainer cage for future experimentation. After a two-hour period it was noticed that two of the salmon had disappeared. Examination of the trout stomach revealed that both salmon had been eaten. This early proof of predation was repeated many times in the laboratory. Experiments of this kind revealed that brook trout only slightly larger than the salmon were capable of capturing them. On one occasion a trout with a length of 7.9 cm. was found swimming about with the tail of a 3.4-cm. salmon projecting from its mouth.

Predation on underyearling salmon by brook trout under normal stream conditions was observed on numerous occasions. On several occasions during planting, fry planted in pools were seen to be readily swallowed by larger brook trout. In order to demonstrate predation by trout, underyearling salmon were frequently thrown into pools along the stream containing larger trout, which usually took them with little hesitation. From observations under both laboratory and stream conditions, it must be concluded that brook trout preyed heavily on fry and underyearling parr when the opportunity arose.

No evidence of predation by brook trout on yearling salmon was gathered although it may be supposed that larger trout would constitute potential enemies. The extent of predation on yearling salmon by large trout would be limited by the small number of brook trout over 10 inches resident in the stream system.

COMMON SHINER (*Notropis cornutus*). This species of cyprinid, although infrequent in the colder waters characterized by brook trout populations, was relatively abundant in the pools of the warmer creek sections. Shiners with length of 10 cm. were common and specimens up to 19 cm. were occasionally captured.

Predation by shiners on the planted salmon was first observed during the planting of fry in 1946. A number of fry planted in pools were immediately eaten by populations of shiners. Following this observation, further laboratory and field observations were made on the predator-prey relationship of these two species.

On several occasions small underyearling parr up to 3 cm. in length were thrown into pools containing shiners of 10.0 cm. and over. In most cases the parr were quickly eaten. Similarly, small parr were eaten by shiners when placed together in an experimental tank. However, under neither stream nor laboratory conditions were shiners observed to capture parr greater than 3.0 cm. in length.

Plantings of salmon fry or small parr in sections containing a shiner population may, therefore, be greatly reduced by predation, usually within a few minutes after planting.

CREEK CHUB (*Semotilus atromaculatus*). This species is distributed over a great part of the creek system. It is less frequent in the colder waters, but is very common in the warmer waters.

Predation on underyearling salmon by the chub was observed under both stream and laboratory conditions. During planting, and at other times, small parr thrown into pools containing chub populations were eaten by the chub. Similar observations were made in experimental tanks. Predation on salmon by creek chub would seem to have been limited to only the fry and small parr. Evidence of this predation was sufficient to prove its importance as a cause of salmon loss in the pools of a large part of the creek system.

BROWN TROUT (*Salmo trutta*). The number of brown trout in the creek system was extremely low. Their distribution was limited to sections V, VI and VII of Duffin East below the Greenwood dam. This species was seldom taken by angling but specimens weighing two pounds or more were occasionally caught. Although no evidence was obtained, it would seem probable that young salmon may infrequently have fallen prey to this species.

RAINBOW TROUT (*Salmo gairdneri*). The distribution of this species was similar to that of the brown trout. Upstream movement from the lake was limited to sections V, VI and VII of Duffin East to the Greenwood dam. The Whitevale dam in section VI of Duffin West prevented movement of rainbow trout to suitable waters in that branch. Large rainbow trout were generally present in the stream only during late fall and early spring. Younger trout, usually

underyearlings or yearlings, were resident in the designated parts of Duffin East during time of salmon plantings. Although not abundant, these fish may have captured a few of the small salmon planted in the lower part of Duffin East.

NORTHERN PIKE (*Esox lucius*). A concentration of pike occurred about the stream mouth where there appeared to be a more or less continuous movement between the lake and the marsh. The distribution of pike extended from the mouth to section II of Duffin Creek.

During the operation of trap nets in section II during the spring of 1948, a number of pike ranging from one to ten pounds in weight were taken. Examinations of the stomachs of these fish revealed that a number of descending smolts had been eaten. For example, the stomach of one four-pound pike contained seven smolts averaging 14.5 cm. in length, as well as four shiners with lengths of 10.0 and 12.5 cm.

Although captures of smolts were probably facilitated by confinement of both predator and prey within the net, it must be concluded that pike were an important predator on the descending smolts as they approached the lake.

OTHER SPECIES. A study of the other species of fish present in the sections planted with salmon indicated that none was a predator on the underyearling or yearling salmon.

No evidence of predation on smolts by species other than pike was obtained. Of the lake fish inhabiting the lower part of the stream, the largemouth bass (*Micropterus salmoides*) and smallmouth bass (*Micropterus dolomieui*) may have possibly preyed on the descending smolts.

BIRDS

It has been shown by White (1936, 1937) and others that kingfishers and mergansers may destroy large numbers of salmon and trout. White stated that the kingfisher may have a predatory potential of more than 50 small fingerling salmon or trout per day, and that the merganser may also rapidly reduce salmon and trout numbers.

Predation on young salmon was considered to be of little importance in its influence on the pattern of salmon survival and distribution in Duffin Creek. The numbers of kingfisher (*Megaceryle alcyon*) were low and only infrequently observed in that part of the stream system planted with salmon. Although mergansers (*Mergus*) were resident in the stream between the lake and section II, they were seldom seen in the planted stream sections and on only one occasion observed feeding in an area planted with salmon. Great blue heron (*Ardea herodias*) were rarely seen except near the stream mouth. The only evidence of predation by this species was gained when a heron was seen to take a yearling salmon and two creek chub from a retainer cage in an open stream not planted with salmon.

Although it is probable that predaceous birds destroyed a small number of the planted salmon, it has been shown that other factors coupled with predation by species of fish largely determined the survival pattern of the planted salmon

during or shortly following planting, and that further mortality during the stream life of the salmon was relatively low. Predation by birds in the planted stream sections, therefore, cannot be considered to have significantly influenced the pattern of salmon survival and distribution.

SHELTER

The amount of shelter within the stream has been established as an important influence on the survival and distribution of the planted salmon. This term may be loosely defined for the purpose of this paper as those more or less permanent local habitat conditions which tend to protect the salmon from harmful factors in its environment.

The study of shelter, so defined, has required a detailed investigation of the habitat of the salmon fry and parr. By continuous observation of the fish from the time of planting until their descent as smolts, it was found that the population of fish which could be supported by a section of stream was dependent on very local conditions, and that the required habitat changed as the fish increased in size.

The following analysis is in two sections: one on underyearling salmon, the other on yearling salmon. The discussion actually considers the ecology of the salmon under tributary and main stream environments.

Underyearling Salmon

TRIBUTARY STREAMS

On being planted in the streams, the small fry seldom moved more than a few feet from the spot where planted. Those planted in the shallow riffly areas oriented themselves into the current and, within a few seconds, settled to the stream bottom. Those not settling on the bottom of the riffles were carried downstream by the current into the pools below. The fry planted in the pools either swam aimlessly about, or if the current was sufficiently strong, oriented themselves into it. On moving to the bottom the fry found any irregularities, such as spaces among gravel and stones, beneath boulders and logs, and among vegetation. Here they became relatively inactive and generally disappeared from view. If suitable resting places were not available, the fry continued to move about or rested in full view of the observer.

The significance of these actions of the salmon in relation to their ultimate survival may be best illustrated by special plantings made in experimental streams A, B and C. These streams were planted with fry at densities varying from 0.3 to 8.0 fish per yard in 1948. The streams were quite typical of tributary streams planted in the general plantings although somewhat superior in character for the survival of salmon. Each averaged about one yard in width and was characterized by a series of unsedimented shallow gravelly riffles alternating with deeper pools. Overhead vegetation was generally limited to grasses, shrubbery, occasional trees, and thin growths of cedar. The average daily water temperature was about 16.0°C. The streams were screened to prevent the movement of fish to or from the study areas.

The fish that were present previous to the plantings were predominantly Eastern brook trout and a few dace. The plantings in these streams were made in early July by which time the underyearling brook trout had grown to sufficient size to become a potential predator on the newly planted salmon. The populations resulting from these plantings were determined in July some two weeks after planting, and again in mid-September. These data are given in Table IX.

TABLE IX. Planting and survival data in experimental streams, A, B, C.

Stream	Length planted	Number planted	Survival data			
			July		September	
	yards		*No.*	*%*	*No.*	*%*
A	809	688	439	63.8	418	60.8
B–1	461	1383	927	67.0	921	66.6
B–2	178	178	57	32.0	52	29.2
C	1128	2769	1611	58.2	1487	53.7
Total	2576	5018	3034	60.5	2878	57.3

From this Table it may be seen that 5,018 salmon fry were planted over some 2,576 yards of the three experimental streams. Surveys made two weeks after plantings showed a population of 3,034 salmon, representing a survival of 60.5 per cent. Similar surveys in September revealed a population of 2,878 salmon which was about 95 per cent of the July population. Thus the greatest mortality occurred within two weeks following the plantings. The relation of salmon survival to the presence of brook trout, previously established as an important predator, was found through an analysis of local survival in all three experimental streams and those tributary streams included in the general plantings.

These observations may be illustrated by the data recorded for experimental stream B, following the planting of 178 underyearling salmon at a density of one fry per yard. The stream area contained 113 yards of gravelly riffles and 65 yards of pools and suported a population of brook trout with lengths from 7.8 to 20.0 cm. The stream averaged one yard in width. The data are present in Table X.

Two weeks after the planting it was found that only 57 out of the 178 salmon were still present, together with 27 brook trout. Of these 46 salmon and one trout were found in the riffles, 11 salmon and 26 trout in the pools. Similar observations of the high survival of very small salmon in riffles with few trout, and their low survival in the pools containing numbers of larger trout were made in all tributary streams supporting brook trout populations. The pattern of survival of underyearling salmon which resulted in these streams has been attributed to predation by the larger brook trout.

When the correlation of salmon survival with brook trout predation was analysed further, it was found that the amount of available shelter which the stream offered the fry was most important in determining the survival or death of the planted fish.

TABLE X. Populations of speckled trout and underyearling salmon in experimental stream B two weeks after planting with salmon at a density of one fry per square yard.

Description of local area	Length of area in yards	Number of fish	
		Salmon	Trout
Riffle	25	18	0
Pool	20	3	6
Riffle	20	13	0
Pool	5	0	1
Riffle	8	4	0
Pool	15	2	1
Riffle	20	6	1
Pool	20	5	5
Riffle	20	5	0
Pool	15	1	13
Total	178	57	27

It was stated previously that those fry planted in the gravelly riffle areas remained there if sufficient protection from current and predators was available. If not, the fish dropped back into pools below. Those fry planted in the pools, or moving there from the riffle where planted, and not able to find some type of shelter were subjected to intensive predation by the brook trout.

The discussion thus far has concerned survival in those areas of tributary streams characterized by brook trout populations. Observations made in the lower parts of the tributary streams where populations of shiners and chub inhabited the pools showed the same effect of the predator-prey relationship on the survival pattern as found in the trout waters. The character and extent of the riffle areas determined the numbers of planted fry which could be supported in them. Similarly, survivals of those fry reaching or planted in the pools depended on shelter from the shiners or chub that were there.

As the summer progressed and the salmon became larger, their habitat requirements changed and they were able to repopulate adjacent planted areas of the tributary streams in which the mortality of fry had been high. The extent of movement was commonly localized to a shift from the shallow gravel riffles to the shelter offered by nearby undercut banks, fallen logs, rubble, boulders and aquatic vegetation.

MAIN STREAMS

A study of survival patterns of underyearling salmon in the main streams, Duffin East and Duffin West, showed that a high proportion of the surviving fry were found in areas of shallow gravelly riffles, but only a small number in the fast riffles or in the pools.

For about two weeks following planting in the main streams, the small fry could frequently be seen just out of the strong current among the gravel and small rubble and seldom in more than six inches of water. Seinings carried out within a fortnight of planting showed only a low survival elsewhere in the deep riffles and in the pools.

Although the faster-flowing riffles were found to offer shelter for underyearling salmon later in the year, fry planted there nearly all disappeared immediately. By experimentation it was found that most of these small fish could not withstand the current and were carried into the pools below. A large percentage of the fry planted in the pools also disappeared as soon as planted. This mortality was caused almost entirely by predation by brook, rainbow, and brown trouts, chub and shiners. As described for the tributary streams, the degree of predation in the pools was largely determined by the amount of shelter available there. The most effective shelter in the pools was offered below undercut banks and around logs and boulders.

Thus habitat conditions in the main streams were such that only a small part of the total area was suitable for the survival of the planted fry. The local areas in which there were good survivals were generally similar in rate of flow and general character to the clean gravelly riffles of the tributary streams.

As the young salmon increased in size they gradually became distributed through riffles with a stronger current and coarser bottom. By late summer they were generally spread over all riffle areas where they could find adequate shelter. Many remained in eddy currents caused by the deflection of the main current around rubble and boulders, and a few settled into the pools.

Yearling Salmon

tributary streams

A comparison of underyearling and yearling salmon populations in the tributary streams, as given in Table V, showed a characteristic drop in numbers for each planting between the autumn of the first and second years. The average yearling populations in each of the tributary streams was found to vary from 47.7 per cent of the underyearling population in Duffin East 3 to 80 per cent in Duffin West 2. This latter stream resembled more closely the two main branches, with but a low loss between underyearling and yearling populations.

A study of the local distribution of the yearling salmon showed them to be present only where suitable habitat conditions existed. By summer and autumn of the second year, the yearling fish had generally left the shallow riffle areas and had become distributed in the deeper water of the pools where shelter was available. Yearling salmon in the tributary streams were not often found to share their local habitat with other salmon or trout.

The study of available habitats for yearling salmon in the tributary streams largely explained the reduction in salmon populations between underyearlings and yearlings. It was shown previously that the shallow gravelly riffles supported a high percentage of the fry and underyearlings which survived following planting. The study revealed that there were not enough such habitats to provide adequate accommodation for a number of yearling salmon equal to the autumn underyearling populations. As a result, a proportion of the salmon on becoming larger had to seek suitable habitats elsewhere.

Comparison of the changes in populations within the tributary streams (Table IV) showed that the loss between underyearling and yearling populations

was less in the lower stream areas than nearer the sources. This may be demonstrated by Duffin East 2 where the average yearling population was 51.7 per cent in area "d" near the source, whereas area "b" near the mouth had a survival of 113.3 per cent of the underyearling population. This latter figure, representing a larger yearling than underyearling population in an area where the survival of fry was comparatively low, may be explained by an analysis of habitat conditions which showed that there were sufficient yearling habitats to amply accommodate the number of smaller fish produced. As a result, a few of the fish produced farther upstream which could not find yearling habitats moved downstream and used available locations there. Yearling salmon were also observed in suitable habitats above the areas planted with fry, thus showing both upstream and downstream movements as recorded in Tables VI and VII.

Characteristically, the larger tributary streams (e.g., Duffin East 2 and Duffin West 2) contained proportionately more suitable habitats for yearling salmon than the smaller waters and hence could support as yearlings a larger proportion of the smaller fish.

MAIN STREAMS

In agreement with findings in the tributary streams, the habitat requirements of the yearling salmon differed considerably from those of the underyearling fish. The yearling salmon generally inhabited fast-flowing riffles and undercut banks usually with a fast flow running alongside. Those in the riffles were usually found near large rubble and boulders where the main current was deflected and where turbulent water hid them from view. Smaller numbers of yearling salmon were found in the pools with deeply undercut banks, or unsedimented roots, logs, or boulders on the bottom.

By reference again to Table IV, it is seen that the average yearling populations in both main streams was roughly 90 per cent of the autumn underyearling populations. Further, it is seen that both branches showed a greater yearling than underyearling population in the lower stream areas in which salmon survived. It should be noted that underyearling survivals were low in these lower areas and high percentage survivals actually represented low numerical increase.

The relatively small changes between underyearling and yearling populations in the main streams may be attributed to a more adequate number of suitable habitats to accommodate the number of yearling salmon produced. Further, by tracing movements of a small number of marked fish, it was shown (Table VII) that some salmon moved downstream into the main streams between the autumn of the first year and the summer of the second year when they were recaptured as yearling salmon. This would further substantiate the theory that a number of yearling salmon which could not be accommodated in the tributary stream attained suitable habitats in the main streams, or in stream sections in which no salmon were planted.

SUMMARY

The importance of suitable habitat and adequate protective cover in influencing the survival and distribution of the planted salmon during their life in the stream has been clearly demonstrated.

The survival of the fry immediately following planting was largely dependent on the amount of clean gravelly areas of riffles available in both main and tributary streams, although requirements varied slightly within the two stream types.

Once the populations had become established in the streams, i.e. when the initial mortality was over, it was shown that habitat requirements changed as the fish increased in size. Of importance was the fact that the tributary streams did not offer sufficient habitats for yearling salmon to support the populations produced by the plantings. In contrast the main streams, and to a lesser extent the large tributary streams, contained sufficient suitable habitats to accommodate the numbers of yearlings which survived through the fry and underyearling stages.

BOTTOM SEDIMENTATION

Creek Conditions

The degree of sedimentation of the bottom varied greatly over the creek system, ranging from locations free of sediment to those where the underlying gravel or other types of bottom were entirely covered by deposits of sediment.

As local variations in sediment deposition were dependent on local changes in gradient and a corresponding change in the rate of flow, a riffle area might be more or less free of sediment whereas the pool below would be heavily sedimented. For this reason, the assessment and comparison of the degree of sedimentation over the creek system was based on observations made in riffle areas having a water velocity of about 2.0 feet per second.

For the purpose of general comparison, the amount of sedimentation has been used to distinguish the following three types of bottom:

(1) *Totally sedimented*: the original bottom of gravel and/or rubble completely covered with sediment.

(2) *Heavily sedimented*: the spaces around the gravel and/or rubble filled in with sediment.

(3) *Unsedimented*: the spaces around the gravel and/or rubble not, or only slightly, filled in with sediment.

On the basis of this classification sections of 10 square feet of bottom were selected and studied in each of the experimental sections from the upper limits of planting to the lake. The marked variation in the degree of sedimentation from section to section was sufficient to permit classification on this basis.

Total sedimentation was found in the millponds above the Greenwood dam in section Duffin East VII, the Whitevale dam in Duffin West IV, and the dam in section Duffin West X-B. Total sedimentation also characterized the lower part of the creek system from section II, where the gradient dropped abruptly to the lake from about 50 to 17 feet to the mile. Near the mouth the stream broadened into a large heavily sedimented marsh.

The remainder of the creek system over which salmon were planted was generally classified as unsedimented to heavily sedimented. The upper stream riffle sections of Duffin East and Duffin West may be termed unsedimented. The same conditions hold for the tributary streams. In all streams the gradual increase in the degree of sedimentation of the riffle areas as the stream was descended to

the mouth made it impossible to define a point where the streams became heavily sedimented.

However, a comparison of the two main streams showed that Duffin East did not become heavily sedimented until Sections IV and V were reached, whereas Duffin West had become heavily sedimented much farther upstream in sections VII and VIII. Although the tributary streams had a relatively unsedimented upper area and a heavily sedimented area near the mouth, the length of stream over which the transition occurred varied from stream to stream.

A study of local variations in bottom sedimentation of all streams showed the pools to be generally heavily sedimented even in those stream sections in which the riffle areas were relatively free of sediment. Deposition of sediment in riffle areas was often found in association with eddy currents near boulders, logs and other obstructions on the stream bottom. Local deposits of sediment were often noticeably altered by even light summer freshets.

The description of bottom sedimentation thus far has been of a qualitative nature. A number of quantitative determinations were also made of the amount of sediment deposited at representative locations over the creek system. Measurements were made by means of small glass collectors, measuring 7.5 cm. in diameter and 2 cm. in depth, which were placed in riffly areas with a water velocity of 2.0 feet per second and a depth of six inches. The collectors were left in the stream for 336 hours (or two weeks) at a time. The material collected was air dried for 24 hours at 100°C. and then measured. Although the accuracy of the procedure was limited by inability to exactly duplicate the sets at different locations, after considerable experimentation the above method was found to yield results sufficiently accurate for comparative purposes.

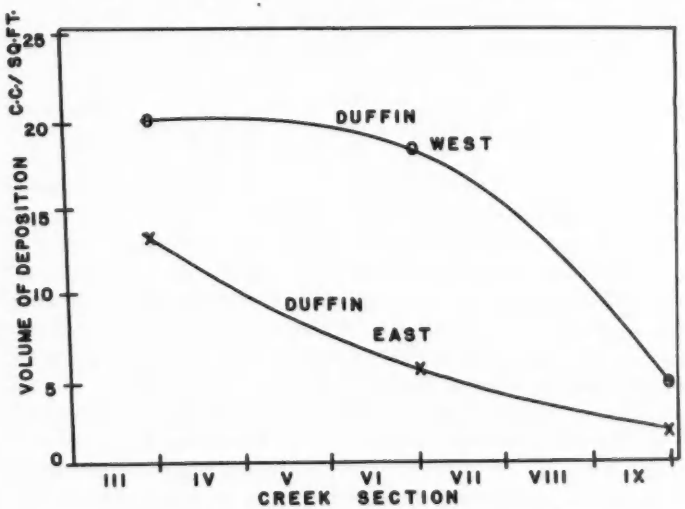

FIGURE 8. Volume of sediment deposited at similar locations in Duffin East and Duffin West over a two-week period.

A comparison of the volume of sediment deposited in Duffin East and Duffin West at locations equidistant from the mouth over a period of two weeks is presented in Figure 8. From this graph it may be seen that at points equidistant from the mouth, the riffle areas of Duffin West were more heavily sedimented than Duffin East. There was a pronounced increase in the degree of sedimentation in Duffin West between sections IX and VI. Below section VI the increase was less pronounced. In Duffin East, however, the degree of sedimentation increased moderately from section IX to section III. The measurements in section II were made below the junction of the two streams and just below the point where the current became reduced. Here there was a marked increase in deposition over that of either branch. This condition prevailed to the stream mouth. Finally, a comparison of both branches shows that the amount of sedimentation in Duffin East III and IV was similar to that in Duffin West VI and VII, sections considerably further upstream.

Observations on a typical tributary stream, Duffin East 2, were made following two weeks of clear weather and two weeks of intermittent rain. These resulting data showed a much larger deposition of sediment in the lower part of the stream under both normal and freshet conditions.

An analysis of sediment samples taken over the stream system identified the sediment deposited as largely silt and fine sand. However, in the relatively unsedimented gravelly bottom source streams, sedimentation was generally caused by a movement of the fine gravel along the stream bottom.

Effect on Salmon Survival

It has been shown in a previous section that the shelter offered by shallow gravelly riffle areas was the only satisfactory habitat for the high survival of planted fry in all streams. In the general description of the relative extent of sedimentation over the stream system, the criterion employed was the degree to which these gravelly riffle areas had become sedimented. Areas typed as "unsedimented" were those in which the spaces around the gravel and rubble were not filled in by sediment and hence offered the shelter required by the planted fry. The degree of bottom sedimentation played an important part in influencing the survival and distribution of the planted salmon.

As the amount of sedimentation of the stream bottom increased from the "unsedimented" to "heavily sedimented" condition, the apertures and spaces around the gravel, rubble and other irregularities even in the riffle areas became filled with sediment, until the protective cover offered to the small fry became low, resulting in a high salmon mortality. Thus the amount of sedimentation in the riffle areas largely determined the survival of salmon over the stream system.

It was shown that the survival of the small fry in the pools was low, largely because the absence of suitable shelter for the young salmon resulted in predation by certain species of fish. This lack of shelter was directly caused by the deposition of sediment in the pools sufficiently great to cover generally the gravel and rubble, and fill in the spaces around stones, boulders, logs and the like, to an extent that they could not be utilized by the fry.

This effect of sedimentation of the stream bottom on the survival pattern of the planted salmon through destroying habitat conditions may be seen by reference to Figure 9 in which this correlation is shown for Duffin West. It may be seen (Table II) that there was a decrease in percentage survival of underyearling salmon as Duffin West was descended from section X-A to about the lower limit of section VII, where high lethal temperatures prevented summer populations. Over the same length of stream the degree of sedimentation increased gradually to a condition of heavy sedimentation in the riffle areas through section VII. Of significance also was the increase in the degree of sedimentation in section X-B, caused by a reduced gradient, and the corresponding decrease in the percentage survival of the underyearling salmon. Similarly, Duffin East showed a gradual increase in sedimentation and a decrease in underyearling salmon survival as the stream was descended from section IX to the lower part of section V where lethal temperatures occurred.

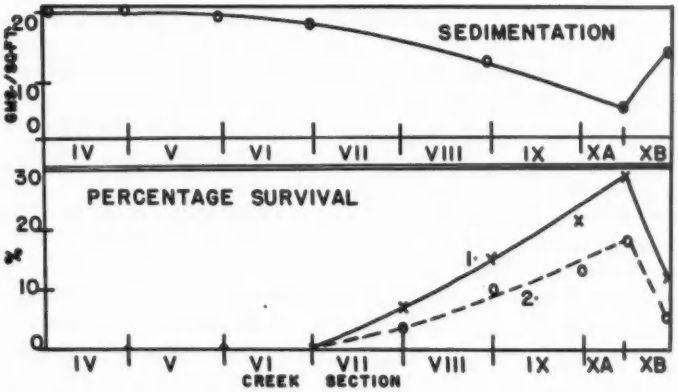

FIGURE 9. A comparison of the sedimentation of riffle areas and salmon survival in Duffin West: (1) Underyearling salmon; (2) Yearling salmon.

The comparison of sedimentation in Duffin East and Duffin West (Figure 8) has shown that the riffle areas of Duffin West had become heavily sedimented through section VII but that this degree of sedimentation was not reached in Duffin East until section V. A comparison of the number of underyearling salmon in these similarly sedimented sections showed autumn survivals of 16.7 per cent in Duffin East, and 14.3 per cent in Duffin West.

The tributary streams, as illustrated by Duffin East 2, showed the same effect of sedimentation on the survival of the planted fry. There was a large increase in sedimentation of the riffles between section "c" near the source and section "a" near the mouth. Survival studies (Table III) showed an average percentage survival for underyearling salmon in section "c" of 23.4 per cent in comparison to a survival of only 2.2 per cent in section "a", an area in which riffle sedimentation was the heaviest observed in that part of the stream system planted with salmon.

From these observations on the correlation of the degree of bottom sedimentation in the gravelly riffle areas with the percentage survival of underyearling salmon, it may be concluded that the effect of sedimentation was to destroy the shelter offered by the riffle areas which was needed for the survival of the salmon fry during and following planting. Sedimentation in the pools resulted in a low survival of fry even in stream sections where the riffle areas were free of sediment and provided excellent habitat for young salmon.

Since the survival studies show that, once the salmon population had become established in the stream as fry and underyearlings, further mortality until the following autumn as yearlings was very low, it would seem that bottom sedimentation did not cause any appreciable mortality of the larger salmon. However, the inability of most of the tributary stream sections with high underyearling survivals to support the same number of salmon in their pools as yearling fish may be attributed largely to sedimentation.

SHADE

A study was carried out to determine the possible effect of shade on the survival of the planted salmon. As the amount of shade cast by trees, shrubbery and the like varied from heavy shade in sections of bush to negligible shade in sections of pasture land, any influence of this condition on the young salmon was readily determined.

The effect of shade in modifying the heating effect of solar radiation on stream water is an accepted fact which need not be expanded here. Although the general character of a stream and its water supply considerably influences water temperatures and the degree of warming, a comparison of the amount of shade over the planted part of the stream system showed that those tributary streams in which lethal summer temperatures destroyed the salmon populations—namely Duffin East 1 and 4 and Duffin West 1—lacked any appreciable amount of shade, whereas those streams with suitable temperatures had a larger proportion of shaded sections.

A comparison of the shaded sections of the main streams showed that Duffin West had considerable areas of partial or heavy shade through sections X and IX but below these sections only a small proportion of the stream was shaded. Duffin East had portions of each section shaded from section IX through to section IV. It would seem that the proportionately smaller amount of shade over Duffin West contributed to water temperatures lethal to salmon in sections VI and V, in contrast to Duffin East where the temperature did not become lethal to the salmon until sections V and IV were reached. Similarly the cumulative effect of non-shaded areas influenced the gradual increase in water temperatures from source to mouth.

Observations on the relation of the amount of shade to the survival of salmon in those sections supporting salmon populations showed no apparent correlation. High survivals of salmon occurred in both shaded and unshaded areas. For example, Duffin East 5 exhibited a relatively high survival of under-

yearling salmon in section "b", part of which was heavily shaded, the remainder passing through open agricultural land offering little shade. No significant difference in salmon survival between the two sections could be found. Similarly, comparisons of survivals of underyearling and yearling salmon in shaded and unshaded portions of each section in both main streams failed to reveal noticeable variations in survival resulting from this factor.

In conclusion, therefore, it may be stated that the amount of shade over the creek system indirectly affected the survival of salmon through its influence on the warming of the water through solar radiation to the extent that the limits of lethal temperature areas were somewhat modified. However, the presence or lack of shade had no apparent influence on the local survival of salmon, and did not modify the pattern of survival as caused by those other factors previously defined.

ABNORMAL WATER FLOW

Abnormal flow may include two conditions: low water and freshets. Conditions of low water had no effect on salmon survival. All salmon plantings were carried out under what has been termed normal conditions when the stream system was not in flood. The volume of water never fell appreciably below that level in any stream in which salmon was planted.

In contrast, as stated previously, spring thaws and summer and autumn precipitation caused large increases in the volume of the stream water. It was shown that the volume of flow during an early June freshet in 1947 increased more than tenfold in section VI of Duffin East. This increase in flow would be exceeded in the similar section of Duffin West and further downstream in both streams. Spring freshets exhibited similar and occasionally heavier flood conditions.

A study of water conditions immediately following each of the three general plantings showed that freshets occurred within a week after the 1945 and 1946 plantings, but no freshet followed the 1947 planting for a period of three weeks.

A comparison of the underyearling populations in 1945, 1946 and 1947, as given in Table III, showed that the estimated percentage survival in 1947 was slightly higher in Duffin East and considerably higher in Duffin West than in the other years. There would appear, then, to be a correlation of an increased underyearling survival with an absence of post-planting freshets in the main streams. This correlation was not found in the tributary streams.

As the movement of the small fry during periods of freshet could not be accurately determined, the effects of post-planting freshets on their survival was not well established. However, it would seem that the lower survival of fry in the riffle sections of both main streams during 1945 and 1946 was caused by a larger number of fish having been carried downstream by an increased flow of water. The fate of these fish was not established although it may be assumed that many of them were victims of predation in the pools, or were carried into stream sections not suitable for their survival. The fact that the increase in percentage survival in 1947 over the previous plantings was more noticeable in Duffin West

would tend to substantiate this view, as Duffin West was subject to more extensive flooding than Duffin East.

Population studies have shown a movement of some salmon from the tributary streams into the main streams between the autumn of the first year, as underyearlings, and the summer of the following year, as yearlings. Also, yearling populations in the lowest sections of the main streams supporting salmon populations were found to exceed underyearling populations. Although no definite statement may be made, it is probable that the downstream movements of the salmon would accompany either fall or spring freshets. This was indicated by the capture of an underyearling salmon in a trap while it was moving downstream in the lower part of Duffin East during a freshet in November, 1946. Also, Elson (1945) stated that parr were found to move downstream during autumn freshets in the Moser River.

As the study has shown average autumn underyearling populations to represent a survival of some 12.7 per cent of the number planted, and yearling populations a survival of some 9.2 per cent, any possible effect of freshets in causing the loss of salmon between these periods must be considered insignificant in comparison with losses caused by other factors previously described. Rather, it would seem that autumn and spring freshets may have assisted the salmon in their movement to suitable yearling habitats.

In summary, immediate post-planting freshets appeared to have lowered the survival of fry in the main streams, particularly Duffin West, but had no appreciable effect on survival in the tributary streams. While these freshets may have modified the survival of salmon fry immediately following planting, they did not affect the actual pattern of survival and distribution over the stream system which was caused by the interaction of those factors analysed in previous sections, and which was so clearly shown by a study of the autumn underyearling populations. In other words, there is little evidence to indicate that freshets greatly affected salmon survival once the fish had become firmly established in the stream as fry.

FOOD

Food is a basic requirement for the survival and development of any organism. No evidence could be obtained which would indicate that a lack of suitable available food affected the survival of salmon in those sections in which they were planted.

A study of the underyearling salmon in the lethal summer temperature areas, before the onset of lethal temperatures, showed that these fish appeared healthy and were growing at a rate similar to those in other areas. The underyearling and yearling salmon in the non-lethal temperature areas appeared in excellent condition and grew at similar rates in sections with both low and high survivals. The absence of abnormally small or undernourished salmon offered proof that inadequate food was not a factor of non-survival.

A quantitative study of insects in selected locations in Duffin East VI (sup-

porting a salmon population), Duffin West IV (supporting no salmon population), and Duffin East 5 in section "b" (a tributary stream with high survival) was carried out by Knapp (MS) from 1944 to 1947. Knapp showed that each section supported a variety of forms.

As this work by Knapp was limited to several stations within the above-mentioned sections, a qualitative study was made of the bottom organisms in the sections planted with salmon. This study indicated that a considerable population was present in all planted sections. The midges, Chironomidae, generally seemed to predominate. The other most common forms included the mayflies, Baetidae and Heptagenidae, the crane flies, Tipulidae, the water scavengers, Hydrophylidae, and the stoneflies, Perlidae.

As the purpose of the experiment was to study the normal survival of the parr, salmon were rarely taken from the stream. From a study of 37 salmon stomachs, it was determined that a variety of aquatic organisms was eaten. The forms identified included members of the Arachnida, Hemiptera, Coleoptera, Diptera, Ephemeroptera, and Plecoptera.

The possible competition between the salmon and other species of fish for available food cannot be considered of great importance in the survival of the salmon, since it has been pointed out previously that the young salmon received sufficient food during their development in the stream.

SUMMARY

A study of planted Atlantic salmon in the Duffin Creek system was carried out from 1945 to 1949. The effect of stream conditions on the survival and distribution of the young salmon during stream life was analysed. Detailed observations and population estimates were made following the general plantings of salmon fry in June of 1945, 1946 and 1947 when some 35,000 yards of Duffin Creek were planted at a density of one fry per yard. Further observations were made following a modified planting in 1948.

It was estimated that 12.7 per cent of the planted salmon survived until the autumn of the first year, 9.2 per cent until the autumn of the second year. Of the 87.3 per cent mortality in the first summer the greater part occurred soon after planting, but the exact number could not be determined.

Virtually all surviving salmon, representing at least 3 per cent of the number planted in 1946, descended to the lake as smolts during the spring of the third year following planting.

The growth of Duffin Creek salmon compared favourably with that of salmon in Maritime streams.

Each of the general plantings was followed by a similar pattern of survival and distribution. In certain parts of the creek system no salmon survived. Over the balance of the creek system, there was a general decrease in the effectiveness of each planting from the upper to the lower limits of planting.

High summer water temperatures were lethal to the salmon in those sections of the creek system where a total disappearance of salmon was recorded.

In that part of the creek system with non-lethal water temperatures, a correlation was observed between salmon survival and maximum water temperature. However, variations in maximum water temperatures did not affect survival although they may have modified slightly the rate of salmon growth.

Although a correlation was observed between a general decrease in salmon survival and increased turbidity from upper to lower stream sections, the turbidity factor was not found to harm the salmon but rather may have buffered the effect of predation on descending smolts.

As the highest mortality in non-lethal temperature areas occurred in the immediate post-planting period, the effectiveness of each planting in producing parr, and ultimately smolts, was determined by the survival of fry.

A study of the general correlation of decreased salmon survival with increased sedimentation of the creek bottom showed sedimentation to be an important factor in survival.

Substantial survivals of fry were limited to gravelly riffle areas where depositions of sediment had not destroyed the shelter offered on the creek bottom.

Low survivals of fry in the pools were caused by predation by certain species of fish, particularly the Eastern brook trout, the creek chub, and the common shiner. This predation was facilitated by a lack of suitable shelter resulting from the heavy sedimentation of the creek bottom. Predation by birds was considered of little consequence in Duffin Creek.

The amount of suitable shelter offered the fry in the riffle areas decreased with a general increase in bottom sedimentation downstream towards the mouth of each creek, resulting in a corresponding decrease in the survival of fry and reflected later in the pattern of survival and distribution exhibited by underyearling and yearling salmon. Those fry planted in riffle areas offering inadequate shelter for the number planted were carried downstream into the pools below where they suffered from heavy predation.

The shelter requirements of the salmon gradually changed as the fish increased in size. A notable shift from underyearling to yearling habitats occurred between September and the following spring. Although movement to new habitats was generally very local, an insufficiency of yearling habitats in those sections of the tributaries with a high survival of fry appeared to cause a movement of salmon downstream into the main branches, where sufficient yearling habitats were generally available.

Immediate post-planting freshets appeared to reduce somewhat the survival of the young salmon in the main branches. Freshets after this time did not alter noticeably the survival of underyearling salmon. The movement of salmon from underyearling to yearling habitats may have occurred at the time of fall or spring freshets.

The absence or extent of shade over the water had no apparent influence on the local survival of salmon, although a paucity of shade in certain areas no doubt contributed towards lethal summer water temperatures.

There was no evidence of any lack of food for the salmon in any part of the creek system.

The other stream conditions studied were not found to significantly influence salmon survival or distribution.

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Bottom Temperatures on the Scotian Shelf[1]

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ABSTRACT

The temperature regime at any point on the bottom over the Scotian Shelf depends upon the geographic location and the depth relative to the structure of the water column. Seasonal variations are observed on any bottom sufficiently shallow to lie within the surface layer. For this reason some areas exhibit maxima in the late fall when the surface layer is deepening. Deeper areas are subjected to non-periodic variations which are related to such factors as slope water incursions and the westward protrusion of Labrador waters. The distribution and variations of temperature over these important fishing grounds are of considerable biological significance.

INTRODUCTION

As part of the programme of the Atlantic Oceanographic Group, observations are regularly made over a fixed network on the Scotian Shelf as shown in Figure 1. Along all lines of the network closely spaced series of bathythermograph observa-

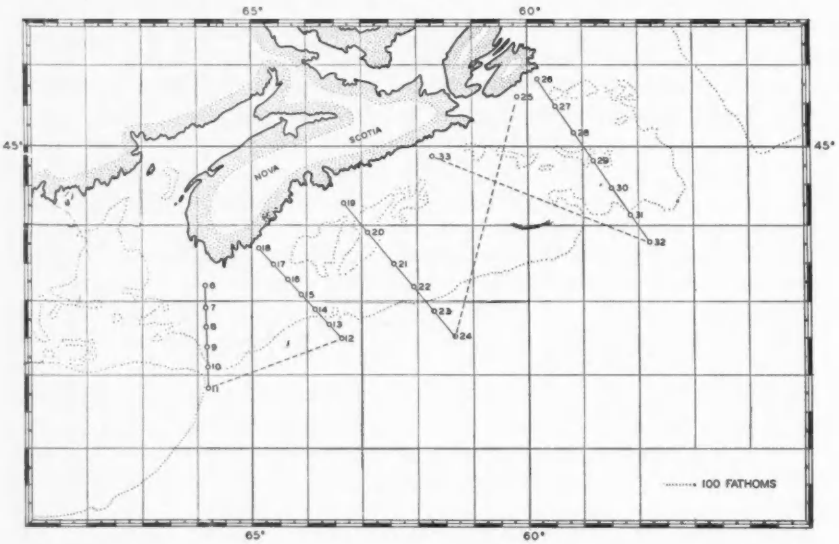

Figure 1. The Scotian Shelf showing network of hydrographic stations occupied during seasonal cruises.

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tions are made, while at the numbered locations full hydrographic stations are occupied. An attempt is made to cover the complete network four times in the year, representative of the four seasons in the sea.

Bathythermograph lowerings are usually made to bottom where the depth permits, or sufficiently close to bottom so that no large error is introduced if the deepest recorded temperature is considered to be identical with the bottom temperature. The recorded data therefore include large numbers of bottom temperatures for discrete locations and times, while the variation in bottom temperature along the survey lines is shown by the vertical temperature profiles into which the data are usually plotted.

The purpose of this article is to discuss this important biological parameter with some generalization and to consider to what extent the various areas of the shelf can be classified on the basis of bottom temperature.

BOTTOM TEMPERATURE AND FISHERIES

Many workers have given attention to the correlations between water temperatures and commercial catches of fish. It seems natural to assume that a given species will have a more or less definite range of temperatures within which it will prefer to live. This has been shown to apply to spawning populations of cod, in the Lofoten area, 3°C. to 6.5°C. (Eggvin, 1933), in the Skaggerak area, 4°C. to 6°C. (Dannevig, 1933), and in the Newfoundland area, 3°C. to 5°C. (Thompson, 1943). For feeding populations the situation will be more complex, as factors other than natural temperature preference will be involved. The presence of food in regions where the normally preferred temperatures are not maintained may induce feeding populations to live outside the preferred range. Thompson (1943) has tabulated the best temperatures for catching large cod off Newfoundland as from 0°C. to 3°C. in spring, and from 3.5°C. to 5.5°C. in summer and autumn. MacKenzie (1934) has shown that, on the Scotian Shelf, good catches of cod may be taken at temperatures from —0.5°C. to 15.5°C. He has also shown that, on the basis of laboratory experiments, feeding activity in cod is controlled to some extent by temperature. Tremblay (1942) has shown the existence of an optimum temperature for taking cod on line trawls in the Bay of Chaleur. MacKenzie and Hachey (1939) have shown that the temperature, depth and thickness of the intermediate cold layer on the Scotian Shelf affects the cod fisheries there. Lee (1952) has summarized the reported relations between water temperature and cod fisheries and has examined correlations between these parameters in the Bear Island fishery.

Although the selection of preferred temperatures for fishing operations may increase the chances of obtaining good catches, it is not to be expected that catches will in that way be insured. This will be especially so for bottom feeding fishes, where the nature of the bottom and the extreme range of bottom temperatures will determine what species will be found in quantity among the benthic flora and fauna, and hence the value of the area as a feeding ground. The origin and movement of the waters involved are also factors which must be considered along with bottom temperatures, as they control conditions which will concen-

trate or disperse basic nutrients, plankton, planktonic larvae and other more or less passive forms.

It is not to be expected, then, that the data to be presented will serve for a study of best fishing temperatures, but they may shed some light on the more significant differences between fishing areas on the shelf.

GENERAL HYDROGRAPHY OF THE SCOTIAN SHELF

Hachey (1942) has described the waters of the Scotian Shelf as consisting of three layers with the following characteristics:

Layer		*Thickness (metres)*	*Temperature (°C.)*	*Salinity (‰)*
Upper	Spring	0–85	>5	<32.0
	Summer	20–60		
	Winter	0–115	<5	
Intermediate	Spring	40–85		
	Summer	55–90	<5	32.0–33.5
	Winter	30–85	(generally)	
Bottom		Limited by bottom configuration	>5 (generally)	>33.5

More recent surveys over a wider area on the Shelf have shown this description to be quite adequate. The bottom layer with its warmer, more saline waters, is found only in the deeper portions of the Shelf, while eastward of Sable Island Bank and Middle Bank the intermediate or cold layer extends to the bottom. Temperatures in the intermediate layer are generally found to be higher towards the southwest, indicative of the movement of these waters from the north and east with progressive modification. Hachey (1938) has given a convincing demonstration of the dependency of this intermediate layer on a transport towards the south and west. This layer is usually thicker and colder in the inshore portion, a consequence of the southwest transport. Beyond the banks an intermediate layer with markedly lower temperatures, whose origin probably differs somewhat from that of the intermediate layer over the shelf itself, lies usually against the outer slope of Banquereau and Sable Island banks. This water probably originates as Labrador current water, which, having rounded the tail of the Grand Banks, intrudes into the area, holding close to the shelf (McLellan, Lauzier and Bailey, 1953). This area, too, is coldest in the northeast, frequently displaying temperatures below 0°C. on Banquereau, while it is seldom colder than 3°C. at the western end of Sable Island Bank.

In the southwestern extremity of the area, contiguous to the Bay of Fundy and Gulf of Maine, extremely strong tidal mixing tends to break down the stratification which characterizes the waters on the remainder of the shelf.

Seaward of the coastal waters lies the slope water, a band of warm, saline water which fluctuates greatly in its geographic boundaries and at times transgresses upon the shelf (Hachey, 1953; McLellan, Lauzier and Bailey, 1953). As has been suggested by Hachey (1937) these incursions of slope water seem to

be more frequent in the central, deeper portion of the shelf which he has called the Scotian Gulf.

It will be appreciated then that the temperature regime at any point on the bottom over the Scotian Shelf will depend upon a number of factors such as: (*a*) geographic location, whether in the eastern or western sector of the shelf, whether on the banks or their outer edges, etc.; (*b*) depth relative to the structure of the water column, whether in the upper, intermediate, or bottom layers.

OBSERVATIONS

In Figures 2 to 7 inclusive are shown bottom temperatures plotted in plan from the results of seasonal cruises. The light dashed lines indicate the lines along which observations have been made, and they should be closely observed when studying the portrayed distribution of bottom temperature. A goodly amount of interpretation has been necessary, as the pattern of observation does not lend itself to a detailed study. In particular, the configuration of isotherms in the region of the Scotian Gulf has been largely a product of interpolation, coupled with a knowledge of bottom topography, layer depths, and the configurations obtained by Hachey (1942), whose observation pattern gave better coverage of this area. Where an extraordinary amount of interpretation was involved in drawing the isotherms, they have been shown by dashed lines.

In Figures 2 to 5 inclusive are shown the bottom temperatures from each of four seasonal cruises in 1952, while the results of summer cruises in 1950 and 1951 are given in Figures 6 and 7 and may be compared to the summer cruise in 1952 (Figure 4).

(*a*) Winter 1952

This cruise (S-4) was made between February 15 and March 18, 1952, at the time when local winter cooling could be expected to show its maximum effect. The bottom temperatures observed are plotted in Figure 2.

Bottom water as cold as 1°C. was found in the shallow area along the Nova Scotia coast from Cape Breton to Halifax. Temperatures in the northeast sector ranged from slightly over 3°C. to less than 2°C. with the higher temperatures occurring on the shallow areas of Misaine Bank. On Sable Island Bank temperatures were mostly between 3°C. and 5°C. with the colder areas being towards the north.

The deep water in the Scotian Gulf showed temperatures greater than 9°C., and the elevation of Emerald and LaHave Banks were sufficient to establish temperatures lower than 7°C. on their central portions. Temperatures on Brown's Bank were between 5°C. and 6°C. while the shallow areas of Roseway Bank extended well up into the cold intermediate layer as evidenced by temperatures below 2°C. Temperatures as low as 2°C. were also observed inshore off the southwestern tip of Nova Scotia.

In the Bay of Fundy section, bottom temperatures were between 5°C. and 6°C. except for the deepest waters, which displayed temperatures greater than 6°C.

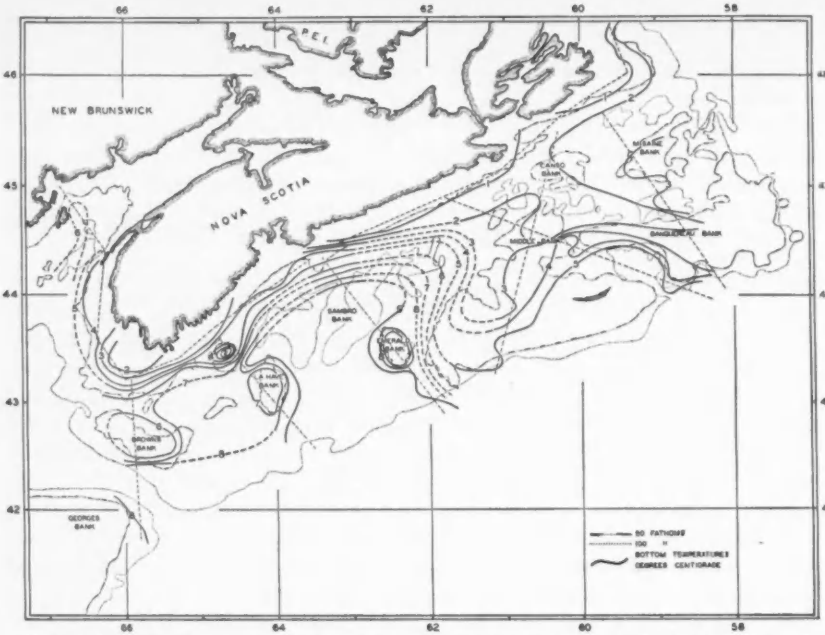

FIGURE 2. Bottom temperatures observed during cruise S-4, February 15 to March 18, 1952.

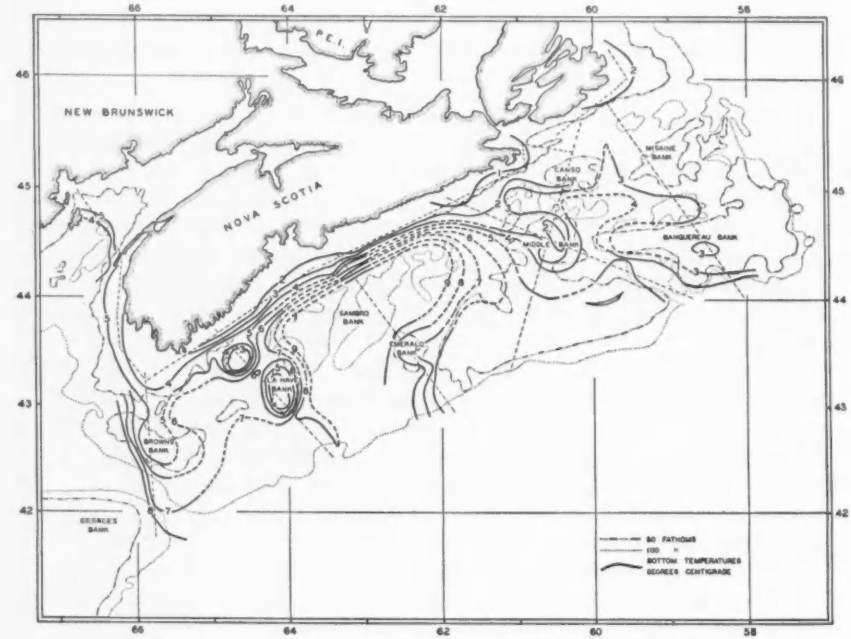

FIGURE 3. Bottom temperatures observed during cruise S-7, April 29 to May 11, 1952.

(*b*) Spring 1952

The spring cruises (S-7) covered the Scotian Shelf between April 29 and May 11, 1952. The observed bottom temperatures are plotted in Figure 3.

All along the Nova Scotia coast, inshore bottom temperatures lower than 2°C. were observed and these were as low as 1°C. in the eastern portion. The northeastern sections of the shelf showed temperatures generally between 2°C. and 4°C. with observations of less than 2°C. on the shallower areas of Canso and Middle Banks. The temperatures over the greater part of Sable Island Bank were between 5°C. and 6°C. The deep water of the Scotian Shelf was still warmer than 9°C. and temperatures on Emerald Bank were generally about one degree higher than those found during the winter cruise, being mainly between 7°C. and 8°C.

The intermediate layer over the southwestern part of the Shelf seems to have been deeper than in the winter, with the result that temperatures were below 4°C. on LaHave Bank, below 5°C. on Brown's Bank, and below 3°C. on Roseway Bank.

In the Bay of Fundy section temperatures had dropped to below 4°C. in the centre of the section.

(*c*) Summer 1952

Cruise S-10 covered the Scotian Shelf in the period August 14 to September 5, 1952. The observed bottom temperatures are plotted in Figure 4.

The bottom temperature on Banquereau, Misaine, and Canso Banks were mostly between 2°C. and 4°C., while on parts of Middle Bank and Sable Island Bank temperatures greater than 7°C. and greater than 8°C. respectively were found. This warming was due to a thickening of the surface layer with the progress of the seasons rather than a change in the temperature or extent of the southwesterly flowing cold water layer, as is shown by temperatures lower than 2°C. in a deep area between Middle Bank and Sable Island Bank.

A tongue of colder water lay against the outer edge of Sable Island Bank giving temperatures below 5°C. there.

Bottom temperatures in the Scotian Gulf were slightly greater than 8°C., about one degree lower than at the time of the winter and spring cruises. Inshore bottom temperatures, on the other hand, were considerably higher, being mainly between 3°C. and 5°C. along the outer coast of Nova Scotia and rising sharply in the Cape Sable area to greater than 9°C. Temperatures on Roseway and LaHave Banks had risen about two degrees to 5°C. and 6°C.

In the Bay of Fundy section the deepest water showed temperatures less than 8°C. while the shallower bottom was as warm as 9°C. and, in the Grand Manan Channel, over 10°C.

(*d*) Autumn 1952

The autumn cruise (S-12) covered the Shelf between October 6 and November 21, 1952. The bottom temperatures observed are plotted in Figure 5.

The coldest water was again found in the northeast sector although only on

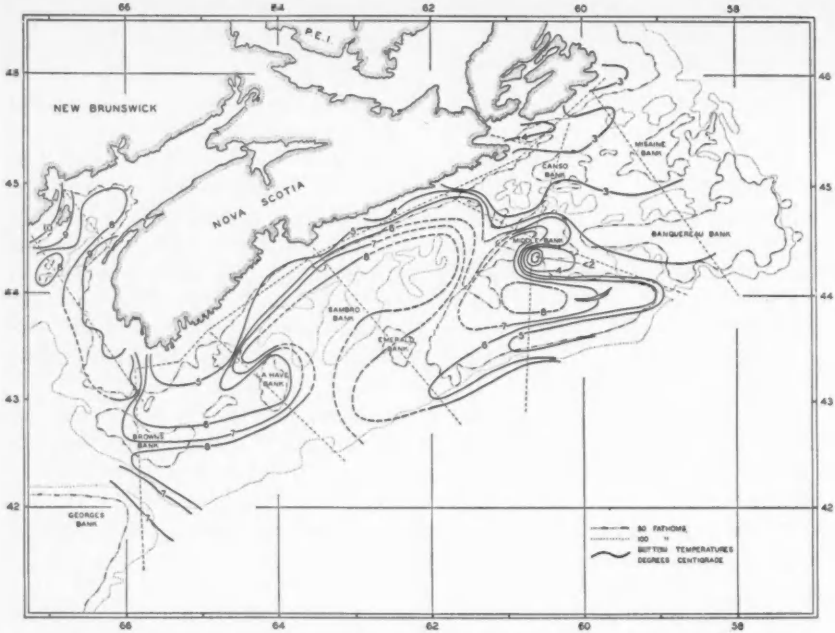

FIGURE 4. Bottom temperatures observed during cruise S-10, August 14 to September 5, 1952.

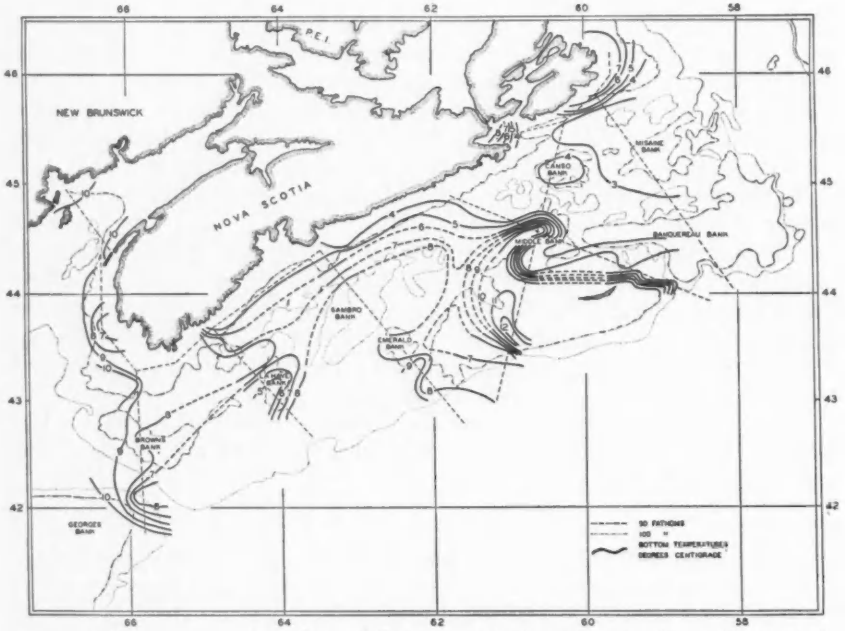

FIGURE 5. Bottom temperatures observed during cruise S-12, October 6 to November 21, 1952.

Misaine Bank was the temperature lower than 3°C. The surface layer had deepened so that Canso Bank showed temperatures greater than 4°C. The inshore pattern was little changed from the time of the summer cruise, except around the eastern corner of Cape Breton Island where temperatures had increased to over 7°C.

The deepening of the surface layer, which is a normal result of surface cooling and the increased winds of the autumn months, had progressed to the point where the shallow waters over Middle Bank and Sable Island Bank were almost uniform from top to bottom. This resulted in bottom temperatures greater than 10°C. A few observations on the western portion of Sable Island Bank showed bottom temperatures greater than 12°C. As the slope water boundary was located quite close to the shelf at that time, this may have been a contributing factor in the establishment of these warm temperatures.

Bottom water in the Scotian Gulf was slightly over 8°C. with a small area outside Emerald Bank greater than 9°C.

Inshore, the temperatures around the southwestern end of Nova Scotia had cooled since the summer cruise to less than 7°C., and those on LaHave Bank had cooled to less than 5°C. In the Bay of Fundy bottom temperatures were mostly greater than 10°C.

(*e*) Summer 1950

The bottom temperatures observed during the summer cruise of 1950 and 1951 are included for comparison with the results of cruise S-10. In Figure 6, the observations from cruise WT-2, between August 16 and August 27, 1950, are shown.

At this time bottom temperatures in the northeast sector were mostly below 2°C. with temperatures below 1°C. in the deep water between Canso, Misaine, Banquereau and Middle Banks. Middle Bank and Sable Island Bank were subjected to the temperatures of the surface layer, to give bottom temperatures there greater than 8°C. and greater than 11°C., respectively.

A cold tongue, with temperatures below 1°C. on the outer edge of Banquereau, extended well into the western part of Sable Island Bank giving temperatures below 3°C. there.

The deep portion of the Scotian Gulf showed temperatures greater than 9°C., while the bottom temperatures of both Emerald Bank and LaHave Bank were those of the intermediate layer, with temperatures below 4°C.

The inshore area all along the Nova Scotia coast showed temperatures below 3°C. with an abrupt transition to over 9°C. in the Cape Sable area. The Bay of Fundy section displayed bottom temperatures from slightly less than 8°C. to over 9°C.

(*f*) Summer 1951

The temperature distribution shown in Figure 7 is from cruise S-2 between September 14 and October 4, 1951. Bottom temperatures were mostly less than 3°C. in the northeastern sector, with less than 2°C. on Misaine Bank and part of

FIGURE 6. Bottom temperatures observed during cruise WT-2, August 16 to August 27, 1950.

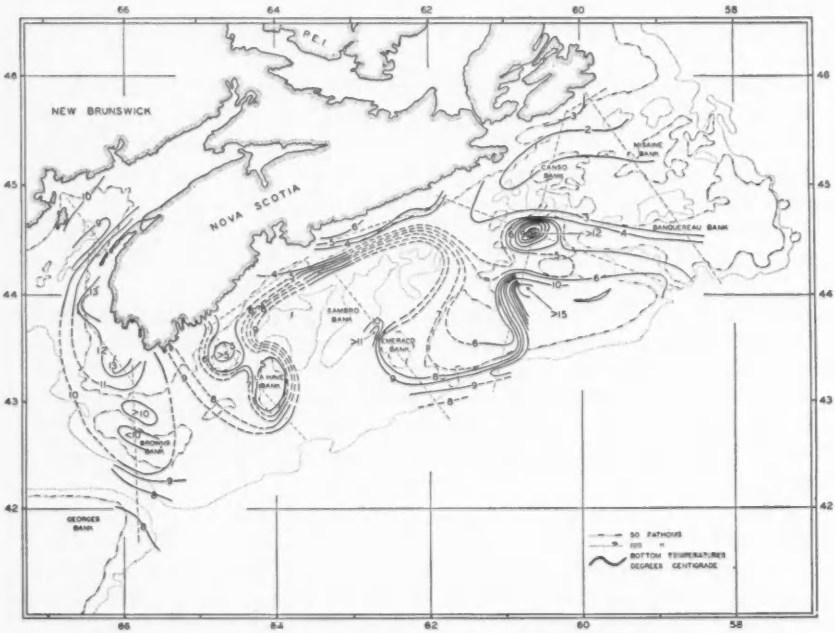

FIGURE 7. Bottom temperatures observed during cruise S-2, September 14 to October 4, 1951.

Canso Bank. The shallower portions of both Middle Bank and Sable Island Bank were subjected to the waters of the surface layer, giving bottom temperatures greater than 12°C. and greater than 15°C.

The deep water in the Scotian Gulf displayed temperatures higher than 9°C., close to the maximum on the continental slope outside Emerald Bank. A small body of water with temperatures greater than 11°C. was found to lie against the bottom on the inner edge of Emerald Bank. This probably represented the product of a slope water incursion.

Bottom temperatures in the whole southwestern portion of the Shelf were higher than observed during any of the other cruises, being close to 10°C. over Brown's Bank and as high as 13°C. inshore in the Cape Sable area. Bottom temperatures were mostly between 9°C. and 10°C. in the Bay of Fundy section.

Vertical Temperature Sections

Three vertical temperature profiles, shown in Figures 8 to 10 inclusive, illustrate a number of features which influence the bottom temperature on the various banks.

Figure 8 represents the vertical distribution from station 25, as shown in Figure 1 (observation 78), to station 24 (observation 61). This section was occupied on August 24 and 25, 1950. This figure illustrates how, when the surface layer becomes deep enough, the temperatures of the shallower portions

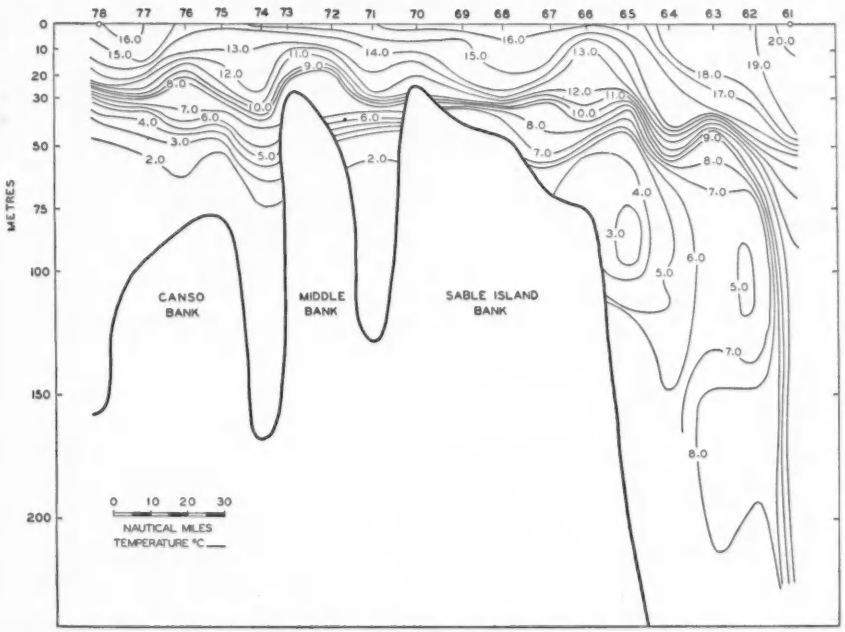

Figure 8. Temperature distribution between Stations 24 and 25: Cruise WT-2, August 24 and 25, 1950.

of the banks sometimes are those of the surface layer. The warm areas near the tops of the banks, and the steep temperature gradients on the slopes are both significant. This Figure also shows a body of cold water lying against the outer slope of Sable Island Bank.

Figure 9 shows the vertical temperature distribution along the line from station 26 to 32 (Figure 1) on November 10 and 11, 1950. It illustrates the persistence of the cold intermediate layer (here less than 2°C.) over the north-east sector of the shelf. Between stations 30 and 31 can be seen the effect of a localized deepening of the surface layer giving bottom temperatures greater than 6°C. and marked temperature gradients along the top of the bank. A patch of cold water (less than 1°C.), was situated against the outer slope of Banquereau Bank. Just inshore of this feature, bottom temperatures were greater than 6°C. and on the offshore side they were greater than 4°C.

Figure 10 shows a section running out from LaHave Bank on November 29, 1951. It illustrates the effect on bottom temperatures which may be produced

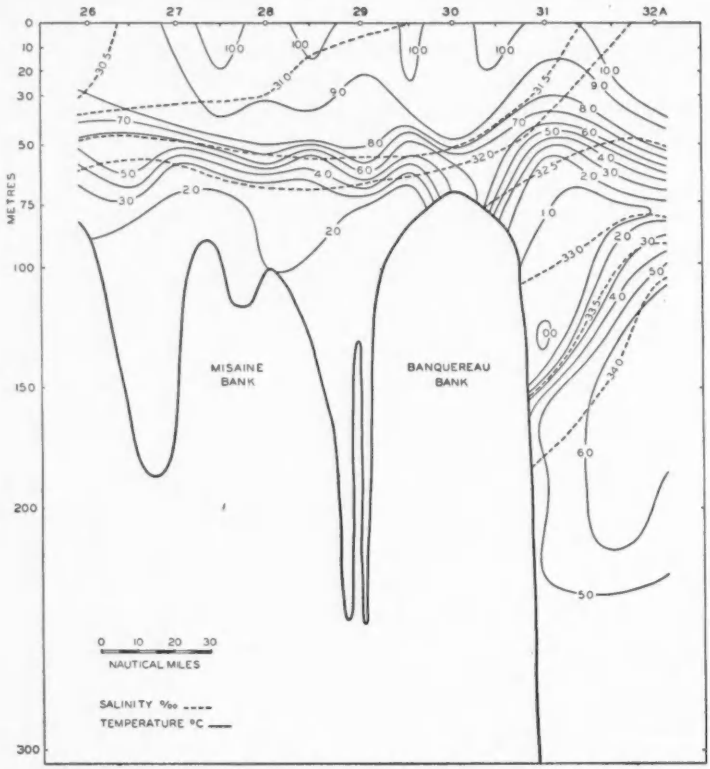

FIGURE 9. Temperature and salinity distribution: Cruise WT-5, Stations 26 to 32A, November 10 and 11, 1950.

when a body of the warm slope water lies close to the continental slope. Where the top of the Bank showed bottom temperatures less than 6°C., temperatures along the outer slope rose rapidly to over 13°C. This type of disturbance of the normal temperature pattern on the banks occurs frequently on LaHave, Emerald, and the western part of Sable Island Banks. As yet no mechanism for predicting these occurrences is visualized.

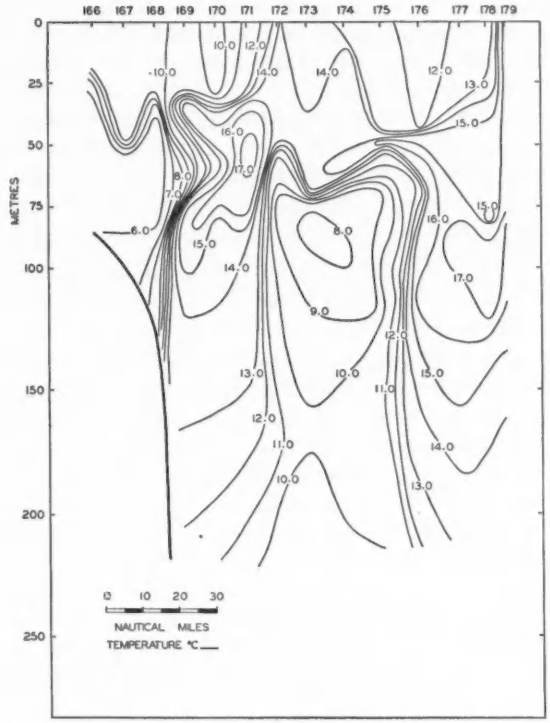

FIGURE 10. Vertical temperature distribution from Lat. 43°03′N., Long. 64°09′W. to Lat. 41°34′N., Long. 62°55′W., November 29, 1951.

DISCUSSION

From consideration of bottom temperatures the Scotian Shelf may be divided into a number of areas each showing a distinctive type of temperature regime.

(*a*) NORTHEAST SECTOR

Comprising Banquereau, Canso and Misaine Banks and the areas between, this sector displays the lowest bottom temperatures on the Shelf. The intermediate layer here reaches to the bottom and its intensity governs the observed temperatures, which range from 0°C. to 3°C. Highest temperatures generally

occur in the autumn. The greatest variations occur on the outer parts of Banquereau, where unusual localized stirring during the warm seasons may elevate bottom temperatures. Here also a tongue of extremely cold water may lie against the outer slope of the bank producing the lowest bottom temperature found anywhere on the shelf.

(*b*) SABLE ISLAND AND MIDDLE BANKS

No data are presented for the shallow waters around Sable Island but it is to be expected that they will partake of the seasonal fluctuation characteristic of the surface layer. Winter cooling will produce near freezing temperatures and a favourable summer season may give rise to extremely warm waters as deep as sixty metres. The deeper parts of these banks generally lie within the cold intermediate layer, and, except for occasions of extreme development of the surface layer, it is in autumn, when mixing has destroyed the thermocline, that warmer water covers these banks at depths up to 75 metres. The southwestern part of Sable Island Bank has perhaps the greatest range of temperatures of any portion of the shelf since it is subjected both to the protrusion of cold water which has been remarked off Banquereau, and to frequent incursions of slope water.

(*c*) THE SCOTIAN GULF

This deep area of the shelf has comparatively steady bottom temperatures which range at least from greater than 9°C. as observed in 1952, to between 6°C. and 7°C. as observed in 1938 (Hachey, 1942). Hachey's observations showed only a small patch of bottom where temperatures were greater than 8°C. in August, 1938. From his 1936 observations (Hachey, 1938, Figures 2 and 4) it would appear that maximum bottom temperature in this area may have been as low as 5.8°C. It is difficult to say to what extent the differences between these observations in the late 1930's and those since 1950, indicate a general warming of the waters on the Scotian Shelf. It is to be expected that changes in the bottom temperatures of this region will take place in a non-systematic manner and perhaps quite suddenly as the interaction of "coastal" and "slope" waters bring varying amounts of deep water in through the channel between Emerald Bank and LaHave Bank.

(*d*) EMERALD, LAHAVE AND ROSEWAY BANKS

These banks lie usually in the bottom layer and exhibit bottom temperatures slightly lower than those in the deeper Scotian Gulf. Departures from these comparatively warm temperatures will be observed when the intermediate layer over this part of the shelf thickens sufficiently to bathe the shallow areas of these banks in colder water. It would appear that this condition is more likely to occur during the summer months.

(*e*) BAY OF FUNDY

The well mixed waters of the Bay of Fundy follow a definite seasonal cycle in temperature with a normal range in the bottom layer from less than 2°C. to over 10°C. (Bailey, MacGregor and Hachey, 1953). The bottom water partakes

of this seasonal variation with minimum temperatures in March and maximum temperatures in October. The deep water in the bay is continually being renewed by an inflow along the deeper channel. This flow will give rise to a decrease in seasonal range in the deepest parts of the bay, these areas being warmer in winter and cooler in summer than the remainder of the bay.

(*f*) BROWN'S BANK

Waters over this bank are largely influenced by the Fundy mixing mechanism. A fairly large seasonal variation is to be expected on this bank although this is complicated by the conflict between the mixed Fundy water and the southwestward flow of stratified waters from the Scotian Shelf proper. Either of these regimes may dominate in determining water conditions on the bank.

SUMMARY

1. The typical three layer stratification of the waters on the Scotian Shelf, and the influence of the slope water and of cold waters to the east, make bottom temperature a complicated function of depth and location.

2. In general the coldest temperatures are found in the northeast sector and the warmest in the deep areas of the Scotian Gulf.

3. Seasonal variation will be observed on any bottom sufficiently shallow to lie within the surface layer. Some areas will, for this reason, exhibit maxima in the late fall when the surface layer is deepened.

4. Slope water incursions show their greatest influence around Emerald, LaHave and the western part of Sable Island Banks.

5. Bands of cold water are frequently observed to lie against the continental slope off Banquereau Bank and aş far west as Sable Island Bank.

6. Bottom temperatures in the Bay of Fundy region exhibit rhythmic seasonal variation.

7. Certain of the deeper banks which lie usually in the "bottom" layer may experience a marked decrease in bottom temperatures when the intermediate layer becomes unusually thick.

ACKNOWLEDGMENT

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Temperature-Salinity Relations and Mixing on the Scotian Shelf[1]

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ABSTRACT

Miller's method of studying mixing processes is extended to the examination of the characteristics of waters on the Scotian Shelf against a five-pointed grid. The use of the modified T-S theorems and the less rigorous definition of water types make T-S analyses rewarding in this area. Some light is shed upon the mixing processes and movement pattern on the Scotian Shelf.

INTRODUCTION

The temperature-salinity diagram introduced by Helland-Hansen (1916) has proved a powerful tool in the description of physical processes in the oceans. With it, waters may be identified as belonging to a given water mass (a definite curve on the T-S diagram), or water masses may be identified as being derived from specific water types (points on the T-S diagram). Wust (1935), for example, has shown how the T-S diagram can be used in tracing Mediterranean waters as they flow into the Atlantic Basin, gradually losing their T-S identity through mixing. Jacobsen (1927) and Stockman (1946) have discussed the theory of T-S curves resulting from the mixture of two or three water types, and have shown how a coefficient of mixing may be determined.

In most cases where T-S diagrams have been discussed, it has been found convenient to use only observations from deeper than some 100 to 200 metres, as "surface data have to be omitted because annual variations and local modifications lead to discrepancies" (Sverdrup *et al.*, 1942, p. 142). Analytical treatment has been mostly limited to cases involving the mixing of no more than three water types. Hence the question arises as to what use can be made of this method in the study of an area such as the Scotian Shelf, where the average depth is approximately 150 metres and at least four water types must be invoked to explain the T-S relationships found.

Miller (1950), in a study of mixing processes over the edge of the continental shelf, where most of the observations were from depths less than 100 metres, introduced a modified concept of the T-S theorems and a method of analysis against a quadrilateral grid. Such concepts and analyses may greatly extend the usefulness of the T-S method in coastal regions. The application of T-S analysis to shallow areas will be useful in a limited area where the mixing processes are proceeding rapidly relative to the influence of such local factors

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as evaporation, precipitation and solar radiation. It is of interest to attempt such an analysis of the waters on the Scotian Shelf during a specific month for the illumination of the mixing processes active in that area.

METHOD

In the usual study of T-S correlation each point on the T-S diagram represents a distinct "water type". It is assumed, or argued, that the T-S distribution of the observed water mass is arrived at by the mixing of a finite number of water types representative of "source regions". At these source regions, water masses must exist which are homogeneous in the temperature and salinity displayed by the terminal point of the T-S curve under consideration, and in sufficient supply to maintain the observed system.

The geometry of T-S curves resulting from the mixture of two and three water types has been treated analytically by Jacobsen (1927) and Stockman (1946). It can be demonstrated that when two water types, represented by points on the T-S diagram, mix in any proportions, the resultant water mass is represented by a straight line joining the two points. Similarly, when three types mix, there result initially two intersecting straight lines which, unless all three types are in unlimited supply, degenerate, as mixing progresses, into curves which can be analytically formulated.

Miller's (1950) method of treating T-S relationships circumvents the necessity of postulating absolute homogeneity of water types. It is sufficient that the points representing the T-S correlations within the water type fall inside a small area on the T-S diagram. The mixing of two water types, so defined, will result in points which lie within the envelope of straight lines joining the two areas. If, then, the points representing data for an area are enclosed by a simple geometrical figure formed by straight lines joining extreme points, and these lines are then divided into equal numbers of equal sections, a grid may be constructed which usefully describes all the waters. Suppose that the figure is a quadrilateral ABCD and that the grid is formed by dividing each side AB, BC, etc. into four equal parts. If each of the extreme points A, B, C and D is considered to represent a fictitious homogeneous water type, then the point A will be touched by a segment of the grid, in which all points could represent water derived of at least 75 per cent A and up to 25 per cent B or D. This segment may now be labelled A and will be termed a water "type" under the less rigorous definition regarding homogeneity. Similarly there will be a segment comprised of from 75 per cent to 50 per cent A with from 25 per cent to 50 per cent B, and this will be labelled "Ab", etc. There will be some ambiguity regarding the origin of waters represented by the central segments in the grid ("Abc", "acD", etc.), but in many cases this ambiguity will be resolved by consideration of the distribution of points within the central segments.

DATA

The data considered are from the observations of the C.N.A.V. *Whitethroat* cruise WT-5 in November 1950. This was one of the series of seasonal cruises

over the Scotian Shelf made by the Atlantic Oceanographic Group (McLellan and Trites, 1951). Thirty-eight stations were occupied in lines over the Nova Scotia banks, across Cabot Strait, across the Bay of Fundy. The locations of these stations are shown in Figure 1. At each station sampling was carried out at standard depths and to the greatest permissible depth, except for the six deep water stations where 800 metres was the greatest depth sampled. Station 24 lay just within the slope water regime and was the only station occupied in the slope water during this cruise.

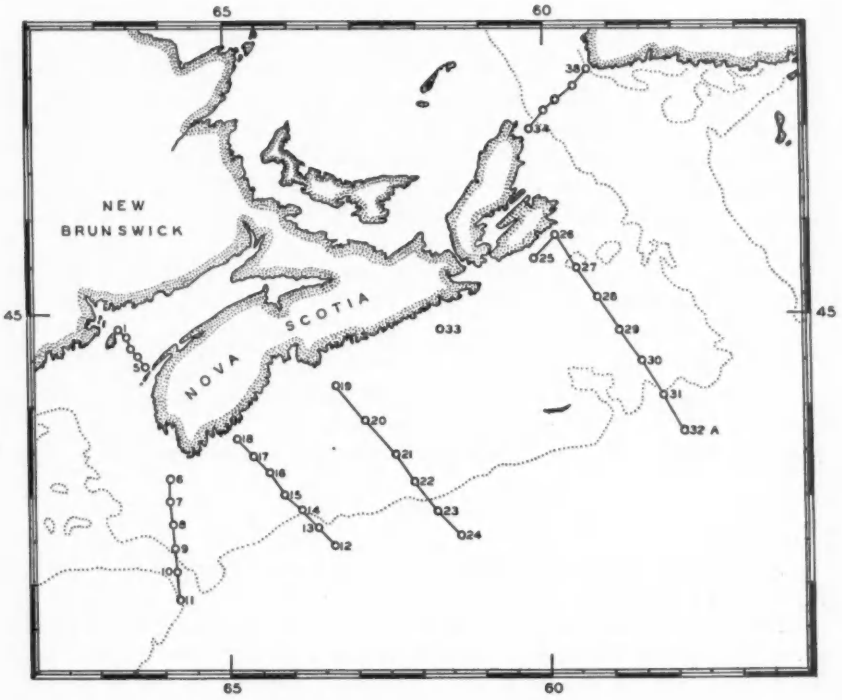

FIGURE 1. Location of stations on the Scotian Shelf occupied during cruise WT-5, November 1951.

Figure 2 shows the scatter of points on a T-S diagram for all stations. Salinities ranged from 30.02‰ to 35.18‰ and temperatures from 0.8°C. to 16.9°C. The heavy dashed line to the right of the figure represents the characteristics of Central Atlantic waters after Iselin (1936). This curve normally forms a limiting curve in the T-S pattern of the deeper slope waters (Iselin, 1936). Curves of equal density (σ_t) have also been shown in the figure.

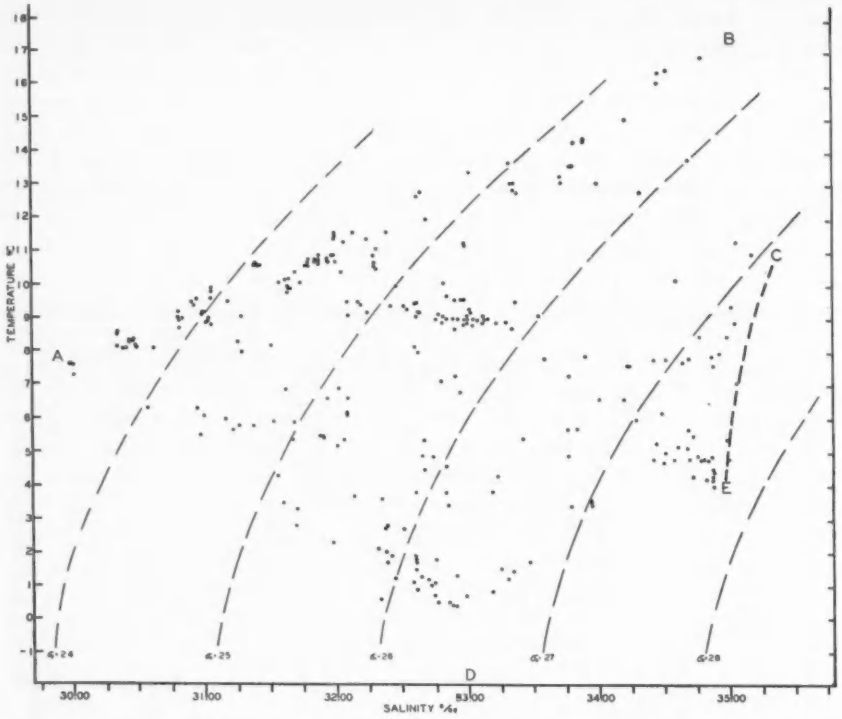

FIGURE 2. T-S diagram showing all samples collected on the Scotian Shelf during cruise WT-5.

ANALYSIS

1. THE GRID

Five points were chosen to bound the area occupied by points on the T-S diagram in Figure 2. They were as follows:

Point A—Temperature 7.8°C., salinity 29.90‰, representative of the surface waters flowing from the Gulf of St. Lawrence, out through the western side of Cabot Strait (Sandstrom 1919, p. 289) and thence over the Scotian Shelf.

Point B—Temperature 17.5°C., salinity 35.03‰, representative of the surface slope water at the time of this cruise.

Point C—Temperature 11.0°C., salinity 35.40‰, representative of the limiting characteristics of slope water at intermediate depths.

Point D—Temperature —1.7°C., salinity 33.00‰, representative of the coldest waters which come around the Tail of the Grand Banks and are sometimes found as far as Banquereau Bank (McLellan and Trites, 1951). No waters of these precise characteristics were observed during this cruise.

Point E—Temperature 4.0°C., salinity 34.97‰, representative of the deeper slope waters.

It must be borne in mind that these points will bound the T-S area only in

so far as the results of this cruise are concerned. Points A and B especially will be subject to seasonal variations. In order that the method of analysis might be valid it is necessary to postulate that mixing, both horizontal and vertical, takes place rapidly compared to seasonal variations. This view is supported by the fact that most of the surface observations fall close to a straight line joining points A and B.

The lack of observations falling in the region between points D and E, and the known origins of these water types, one in the deep slope waters and the other in shallow coastal waters, is sufficient reason to assume that no direct mixing takes place between these waters.

A grid was constructed in two parts (Figure 3) dividing the pertinent area on the T-S diagram into 28 segments. One part of the grid took the form of a quadrilateral ABCD in which each side was divided into four equal parts and the division points joined in a quadrilateral grid. On the side CD a triangle CDE was erected, and each side of this similarly divided into four equal parts.

The segments of the grid were then labelled as shown in Figure 3. In each case the large letter indicates the water type chiefly involved in producing the waters belonging to the segment, while the small letters indicate the type or

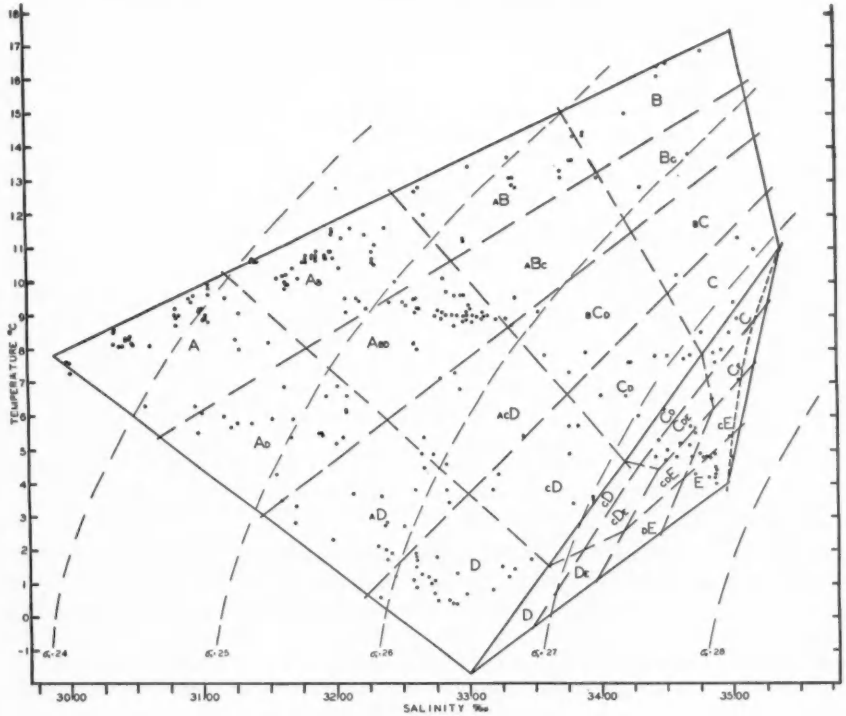

FIGURE 3. T-S diagram with grid superimposed.

types also required to complete the mixture. There is some ambiguity concerning the origin of waters in those segments requiring a three letter label, but this is in part dispelled by the observed distribution of water types. In the section described below (Figures 4 to 9 inclusive) areas where these water types were found, have been indicated by stippling.

2. The Sections

Having constructed the grid and so labelled the water types, the next step in the analysis was to plot the distribution of water types as they occurred in vertical sections. The T-S curve for each station was overlaid with the grid and the distribution of water types with depth recorded. These were plotted in vertical sections in Figures 4 to 9 inclusive.

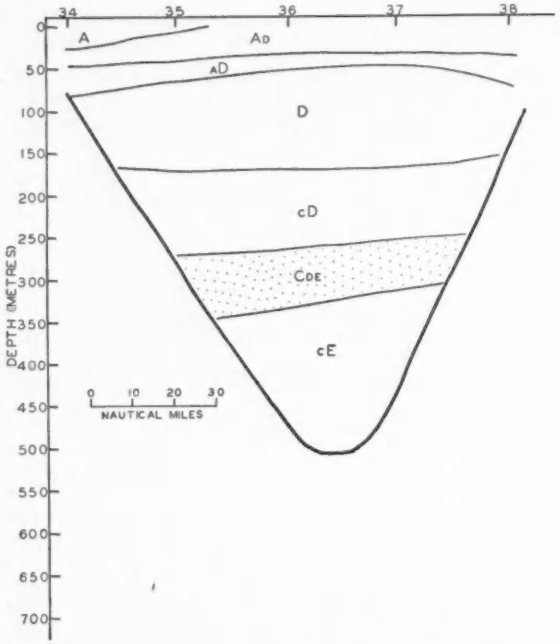

Figure 4. Vertical distribution of water types in the Cabot Strait section.

(*a*) the cabot strait section. This section (Figure 4) shows "A" type water flowing out of the Gulf of St. Lawrence on the Cape Breton side of the Strait. On the Newfoundland side the surface waters are colder and more saline ("Ad"). A layer of "D" water with average thickness of the order of 100 metres covered the whole section at intermediate depths. Below this layer, the sequence of water types was "cD", "Cde" and "cE" showing the combination of "E" water with water formed by a mixture of "D" and "C" waters. The occurrence of

"Cde", "cE" and "E" water at depths less than 500 metres in the slope waters and coastal waters has been interpreted as the result of upwelling of Central Atlantic waters against the continental slope (Iselin, 1936; McLellan *et al.*, 1952).

(*b*) THE BANQUEREAU SECTION. The section shown in Figure 5 ran from the Cape Breton shore out over Banquereau Bank and beyond the edge of the continental shelf. A surface layer of type "A" water covered all but the outer part of the section to a depth of over 40 metres, and a fairly sharp transition lay between this and the "D" water which covered the banks. The "D" water extended more than 40 miles beyond the outer edge of Banquereau. At station 32A, the influence of warm "B" water was shown in the sequence "Ab", "Abd",

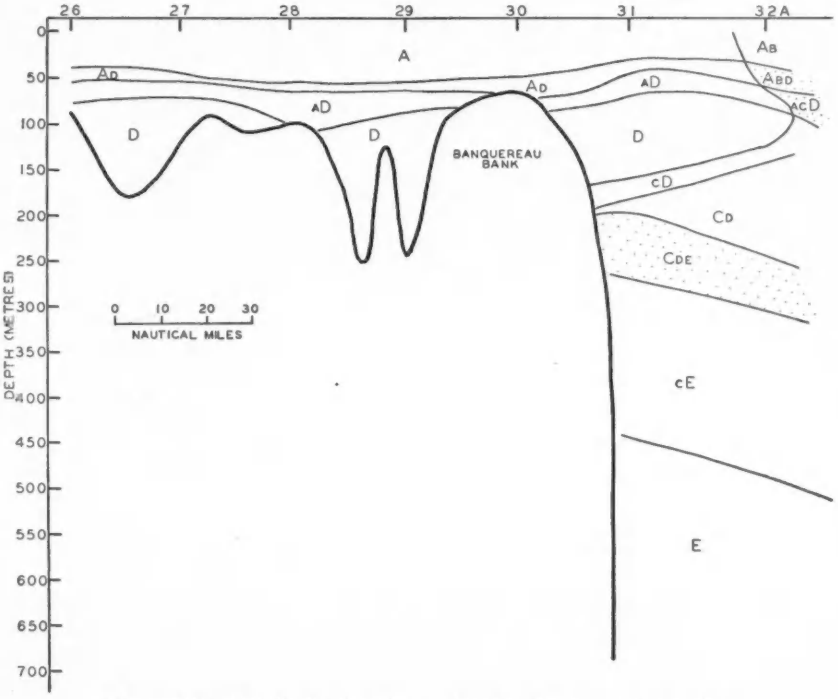

FIGURE 5. Vertical distribution of water types in the Banquereau section.

"acD". In the water deeper than 150 metres, beyond the Shelf, the sequence was "cD", "Cd", "Cde", "cE", "E" showing that "D" and "C" waters mix and there is a deep water addition of "E" water.

(*c*) THE EMERALD BANK SECTION. The section in Figure 6 ran from Sambro Bank over Emerald Bank and beyond. Inside, and over, Emerald Bank the influence of slope water ("B" and "C" waters) was marked in the sequence "Ab",

"Abd", "acD", "cD", and the bottom water was a layer of "Cd", which extended slightly beyond the outer bank. Moving outward, the transition to a pure slope water type is seen in a narrow band with sequence "aB", "aBc", "bCd", "Cd", "Cde", "cdE", "cE", "E", beyond which the sequence is that of the usual slope water. A tongue of surface slope water ("B") was observed to extend in, under the "aB" water, as far as station 22.

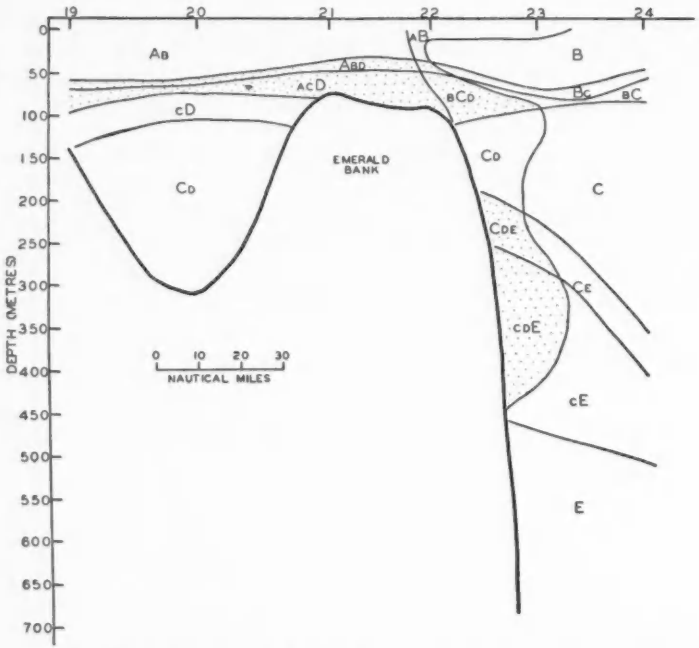

FIGURE 6. Vertical distribution of water types in the Emerald Bank section.

(*d*) THE ROSEWAY, LAHAVE SECTION. This section, running out over Roseway and LaHave banks (Figure 7), showed a greater coastal influence than had appeared in the Emerald Bank section. The occurrence of "Ad" and "aD" water at stations 15 to 18 is indicative either of a flow along the coast which is confined inshore of station 19, or a flow which, having been more general, has been interrupted by the intrusion of warmer waters in the Emerald Bank section. Hachey (1942) has indicated such a continuity in his illustrations of temperature and salinity distributions. This section did not extend to the slope water although stations 12 and 13 showed high proportions of water with "slope" characteristics. Below 200 metres, station 13 showed the slope water sequence, but a more coastal characteristic was observed at station 12 between 200 and 475 metres. These waters ("Cde" and "cdE") are no doubt continuous with those found

close against Emerald Bank and would indicate that these waters flow westward against the trend of the slope water.

(*e*) THE BROWN'S BANK SECTION. The section shown in Figure 8 ran from Cape Sable, over Brown's Bank to the eastern extremity of Georges Bank. The

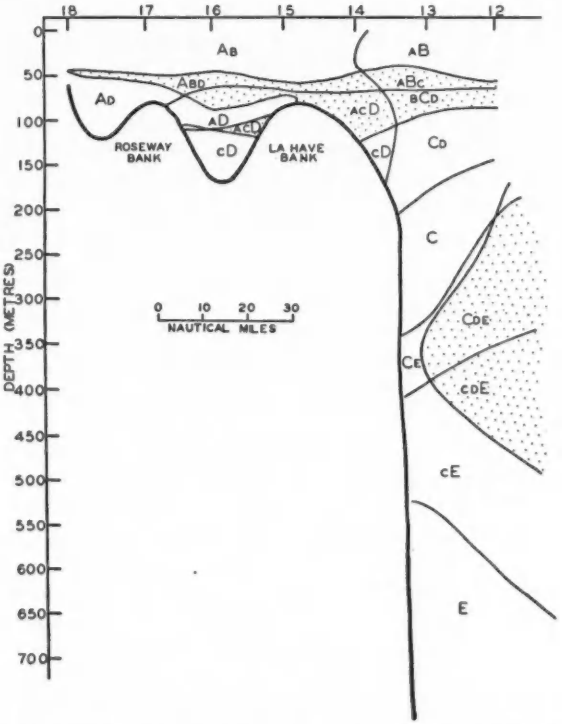

FIGURE 7. Vertical distribution of water types in the Roseway, LaHave section.

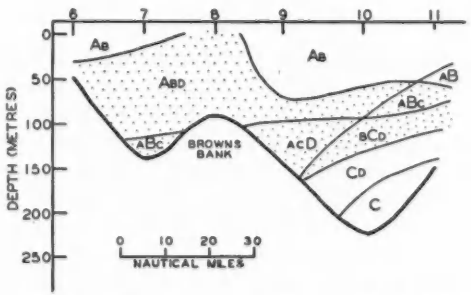

FIGURE 8. Vertical distribution of water types in the Brown's Bank section.

waters in this section are generally well mixed, especially over Brown's Bank. The general sequence of water types is "Ab", "Abd", "acD", with more slope-like waters pressing in at stations 10 and 11. The bottom water inside Brown's Bank ("aBc") appears to be derived from the Bay of Fundy.

(*f*) THE BAY OF FUNDY SECTION. All of the water in the section across the Bay of Fundy (Figure 9) belongs to categories about whose origin it is difficult to be specific. Along the coast of Nova Scotia a surface layer of "Ab" water extends as far as the mouth of the Bay, while the deep Fundian Channel, is fed by "Cd" and "C" type waters through the channel between Brown's Bank and Georges Bank (station 10, Figure 8). The intense tidal mixing in the Bay of Fundy converts these to "Abd", "aBc" and "bCd" waters with "Abd" predominant. Consideration of the density (σ_t) lines on Figure 3, will show that as a result of this mixing surface waters are produced which are heavier than surface waters outside the Bay, while bottom waters in the Bay are less dense than those at similar depth outside. The result must be an outward flow at mid-depths, which accounts for the thick layer of "Abd" water shown in Figure 8, and calls generally for a flow of waters into the mixing system both at the surface and along the bottom. Such a system has been remarked upon by Bigelow (1924, 1928) and by Watson (1936).

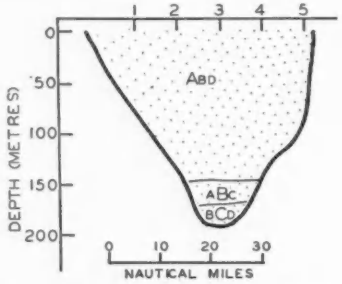

FIGURE 9. Vertical distribution of water types in the Bay of Fundy section.

DISCUSSION

Presentation of the data in this form has some advantages in the formulation of a movement pattern for the area. This is so since a more or less definite region may be designated as the source of each of the five basic categories of water. "A" water flows out the western side of Cabot Strait and covers the surface as far as station 31. As it moves westward along the coast considerable mixing with "B" waters takes place, probably localized in the region of Middle Ground Bank, so that only "Ab" water is found in the three western sections. The "B" and "C" waters are representative of slope water from the surface and mid-depths and have their greatest influence in the Emerald Bank section, and, in the case of "C" water, again in the Fundian Channel. "D" water appears as a strong layer across Cabot Strait and over the banks in the Banquereau section. Its influence

is felt in all sections but is considerably modified by "C" waters in the more westerly sections. "E" water appears only below 450 metres beyond the edge of the continental shelf. Its greatest influence inshore is observed in the bottom waters of the Cabot Strait section, which is indicative of a flow inward along the Laurentian Channel. The efficient mixing brought about by tidal action in the Bay of Fundy is evidenced by the fact that mixture of at least three of the basic water types is required to explain the origin of any water found here. "A", "B", "C" and "D" waters are all necessary for explanation of the complete column.

The grid used in this analysis will of course only be applicable to the single cruise and the water movements inferred do not necessarily hold for all seasons. It is implicit in the method that a condition of simultaneous observations be approximated and that the dynamics be inferred from a static distribution.

SUMMARY

1. A method essentially similar to that used by Miller (1950) makes it practical to use T-S relationships in studies of mixing and circulation of shallow waters.

2. A five-pointed grid was necessary to classify the waters found on the Scotian Shelf in November 1950. The five points were representative of (*a*) surface water flowing out of the Gulf of St. Lawrence on the west side of Cabot Strait, (*b*) surface slope water, (*c*) slope water from intermediate depths, (*d*) cold Labrador water which enters the area by rounding the Tail of the Grand Banks, (*e*) deep slope water.

3. Vertical sections showing water types as designated on the T-S grid show several features of the dynamics of Scotian Shelf waters:

(*a*) The surface water from the Gulf of St. Lawrence floods the eastern portion of the Shelf as far offshore as Banquereau Bank but undergoes significant mixing with surface slope water before appearing in the section to the west of this.

(*b*) Cold water of Labrador characteristics appears as a thick layer in Cabot Strait and over the Banquereau section where it reaches to the bottom, but it also is considerably modified by slope water as it moves towards the southwest.

(*c*) The deep slope water has a significant influence in the waters beyond the Shelf and in the deep waters of Cabot Strait.

(*d*) The efficiency of Bay of Fundy tides as a mixing mechanism is shown by the need to evoke at least three primary water types to explain any of the waters found here.

(*e*) There is evidence of an outflow of mixed waters from the Bay of Fundy at mid-depths.

ACKNOWLEDGMENT

This paper represents work done by the Atlantic Oceanographic Group under the general direction of Dr. H. B. Hachey, Oceanographer-in-Charge, and is published with the permission of the Canadian Joint Committee on Oceanography.

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Distribution of Appendicularians in Relation to the Strait of Belle Isle[1]

By Miklos D. F. Udvardy[2]
Fisheries Research Board of Canada

ABSTRACT

The plankton material collected by the 1923 expedition of the Canadian Fisheries Research Board was examined with regard to appendicularians (Tunicata). Their occurrence supports the thesis that these animals can serve as current indicators, as suggested by previous authors for the same waters. The distribution of the water of the Labrador current around Newfoundland is traced by the occurrence of oikopleurids, and of their separate age classes, in the hauls. The results agree with the hydrographic data of the expedition and with the distribution of other planktonic groups. Partial disintegration of live appendicularians in response to unfavourable environmental conditions was common, especially where waters of different character mix.

INTRODUCTION

The 1923 expedition of the Fisheries Research Board of Canada aimed at oceanographic and biological exploration of the waters related to the Strait of Belle Isle. The expedition took plankton samples from the last of July to the last of August across Cabot Strait, in the Esquiman Channel, in the Strait of Belle Isle, and finally in the open Atlantic north of the Strait; then, during September, along the east and south coasts of Newfoundland. The distribution of the appendicularians in these areas assumed importance when Thompson and his collaborators (1933, 1934, 1935, 1936) published detailed accounts of their distribution in the same area for several years, on which they based conclusions as to the origins of the waters.

MATERIALS

Altogether I have investigated appendicularians from 99 stations, in most cases both from surface hauls and from hauls taken between 20 and 30 m. In many cases material from a deeper haul, or from a vertical haul was also investigated. In the case of 55 hauls I examined the complete plankton samples; further I had available appendicularian material from 169 hauls that had already been sorted. All the hauls studied were taken with the No. 0 net.

Pinhey (1927a, b) published records for the occurrence of these forms in most of the hauls taken at about 7 m. depth taken with the No. 5 net. Comparison of her data with mine shows that there are some stations where I found *Oikopleura* species on the surface while they were lacking in the 7-m. hauls, and again Pinhey found *Oi. vanhöffeni* at 12 stations (15, 16, 18, 19, 22, 55, 58, 72, 103, 408/Sept., 409/Sept., 449)[3] where I have no such data. The lack of the quantita-

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[3]Numbers in parenthesis indicate the numbers of stations. Nos. 1 to 103 are *Arleux* stations, Nos. 408 to 451 are *Prince* stations.

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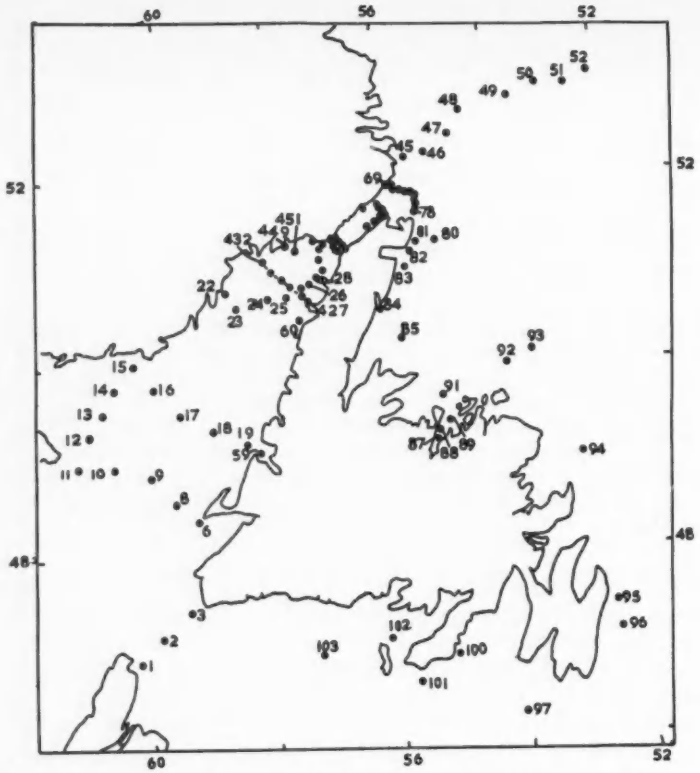

FIGURE 1. Map of the region covered, showing locations of the *Arleux* (1 to 103) and *Prince* (408 to 451) stations occupied in 1923 in the Strait of Belle Isle and around Newfoundland.

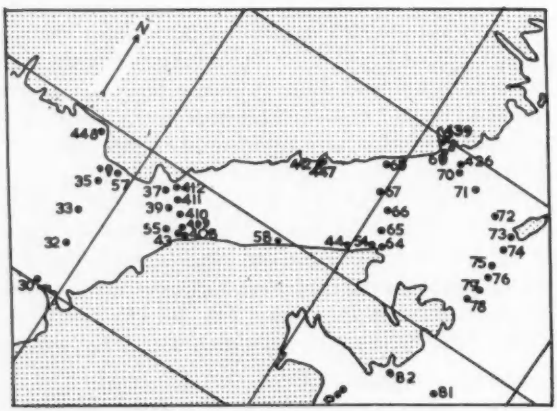

FIGURE 2. Map of the Strait of Belle Isle showing locations of the *Arleux* (30 to 82) and *Prince* (408 to 448) stations occupied in 1923.

tive data of occurrence of these 12 hauls does not alter the conclusion drawn in the following.

In the case of *Fritillaria borealis*, Pinhey had data from many more stations than I have had. All the available data are summarized in Figure 3.

Of the four appendicularian species known from the area, *Oikopleura vanhöffeni* Lohm. occurred most frequently. According to Thompson (1936) this species is an indicator of the cold water of pure arctic origin. I found in the hauls even large amounts of *Oi. labradoriensis* Lohm. the other species known as dwelling in the mixed cold-temperate water of the northern oceans. *Oi. dioica* Fol, the characteristic species of the temperate waters especially over shallow continental banks, was not found. Of *Fritillaria borealis* Lohm., only the varietas *typica* Lohm. occurred, and in the plankton samples investigated it was never as abundant as at the stations of Thompson and his collaborators.

Table I (see appendix) shows what appendicularians were found at the various stations. The positions of the stations are given in Figures 1 and 2.

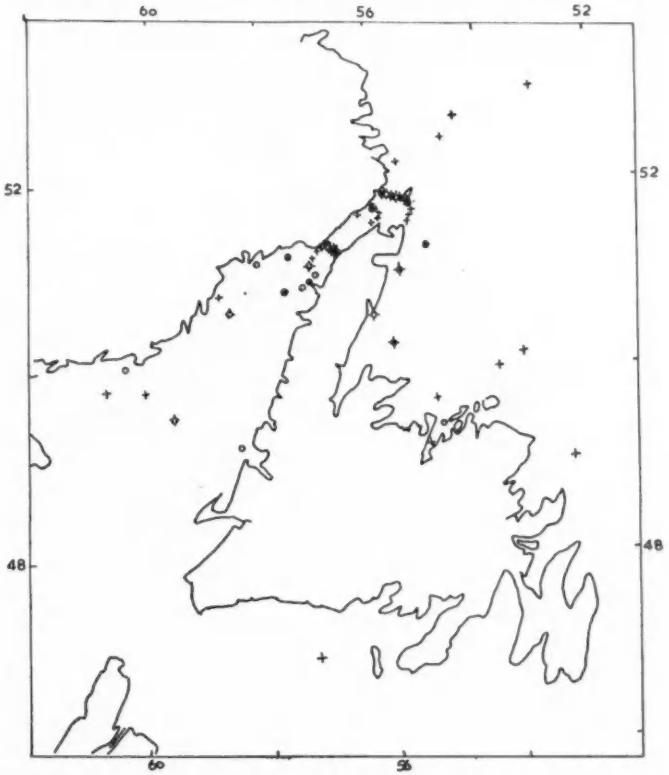

FIGURE 3. Distribution of *Fritillaria borealis*, as found in plankton hauls taken at the surface (solid circles), at 7 m. (crosses) and at 20–30 m. (open circles).

August Hauls

In the inner part (45, 46, 47) of the traverse taken north of Belle Isle out into the Atlantic off Double Island, only *Oi. vanhöffeni* occurred and in small amounts. In the outer half of this traverse (48, 49, 50, 51, 52) it is completely lacking, and here *Oi. labradoriensis* occurs in small numbers at some of the stations. Thus *vanhöffeni* has to be considered as an indicator of the inner part of the Labrador current, as far as August hauls are concerned. Likewise I assume that the occurrence of *vanhöffeni* alone indicates that the water of the haul originates unmixed from the Labrador current ("Arctic" water).

At the surface (Fig. 4) we are able to trace such Arctic water in the Strait of Belle Isle around Watts bight (44), then on the north side of the Strait at Amour Point (411, 412), Shekatika Bay (432) and station 33 situated in the middle of the inner end of the Strait, as well as on the north shore of the

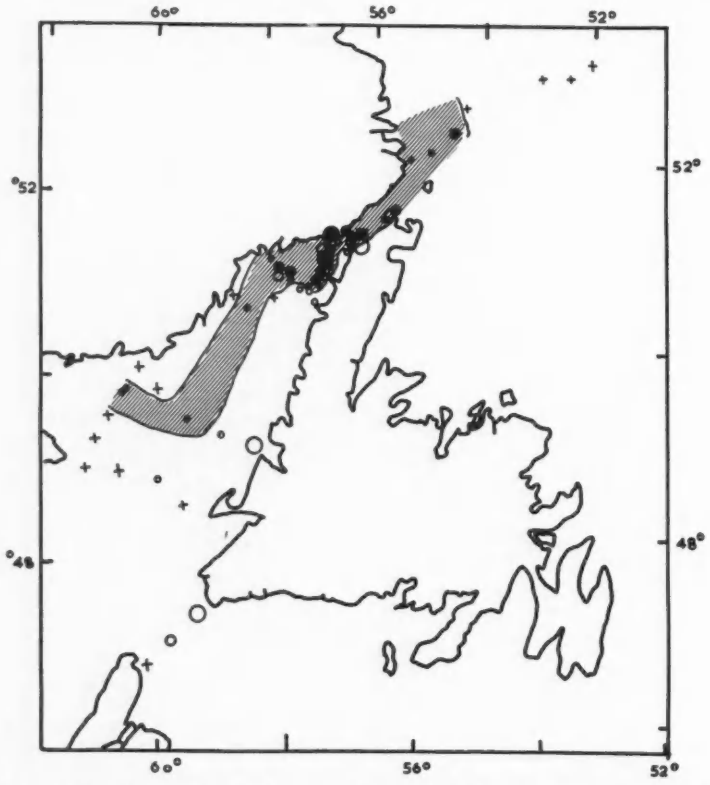

Figure 4. Distribution of *Oikopleura vanhöffeni* (solid circles) and *Oi. labradoriensis* (open circles) in surface plankton hauls of August, 1923. Small circles indicate 1–9, medium circles 10–99, large circles 100–499 and squares over 500 specimens per haul. A cross indicates a haul with no *Oikopleura*. Lined areas represent occurrence of *Oi. vanhöffeni* in surface hauls.

Esquiman Channel inside. In the traverse between Amour Point and Savage Cove (412 to 408), *vanhöffeni* still occur everywhere, whereas to the south, stations along the coast of Newfoundland (55, 427) containing only *labradoriensis* indicate water of the Gulf of St. Lawrence ("Gulf" water) that has drifted northeastward from near the Bay of Islands (18, 19). The occurrence of some *vanhöffeni* at stations 23, 17 and 14 might indicate that although the surface water here is no cooler than that of the surrounding stations, the mixed and warmed water of the Labrador current here still is on the surface in a narrow strip, between the warm surface water at the east end of Anticosti Island and the coastal water along the north shore, neither of which seems to contain appendicularians near the surface.

In the 20- to 30-m. hauls (Fig. 5) in the Strait of Belle Isle the conditions are largely the same as near the surface. However, *vanhöffeni* occurs generally in much larger amounts and the numbers found indicate that a large quantity of them floated between Amour Point and Savage Cove in the central and southern

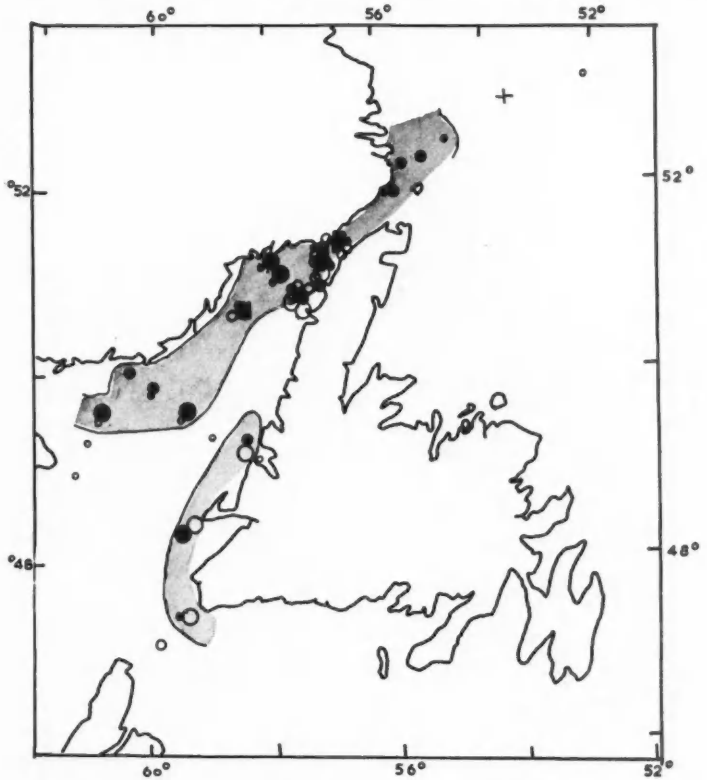

FIGURE 5. Distribution of *Oikopleura vanhöffeni* and *Oi. labradoriensis* in 20–30 m. plankton hauls of August, 1923. Symbols are as in Figure 4, with the closely stippled area representing occurrence of *Oi. vanhöffeni* in 20- to 30-m. hauls.

parts of the Strait and around station 33. The results of the traverse from station 427 to station 432 (between Rich Point and Shekatika Bay) emphasize still more than the surface hauls that here the water of more arctic origin is near the northern coast of the Channel, and close to Rich Point *labradoriensis* occurs in maximal amounts. Southwestward in the Channel a somewhat stronger effect of the Labrador current is shown at station 23, with continuation near the north shore, particularly at stations 17 and 13.

The occurrence of *vanhöffeni* on the Newfoundland side of Cabot Strait, off Cape St. George and off the Bay of Islands could be considered—in agreement with Thompson and Frost's chart of the general course of the Labrador current —as the end of its last branch around the south coast of Newfoundland.

The results of the deep (over 30 metres) hauls (Fig. 6) merely complete the above picture regarding the Strait of Belle Isle and the northern part of the Esquiman Channel. The rather uniform occurrence of *vanhöffeni* in the depths

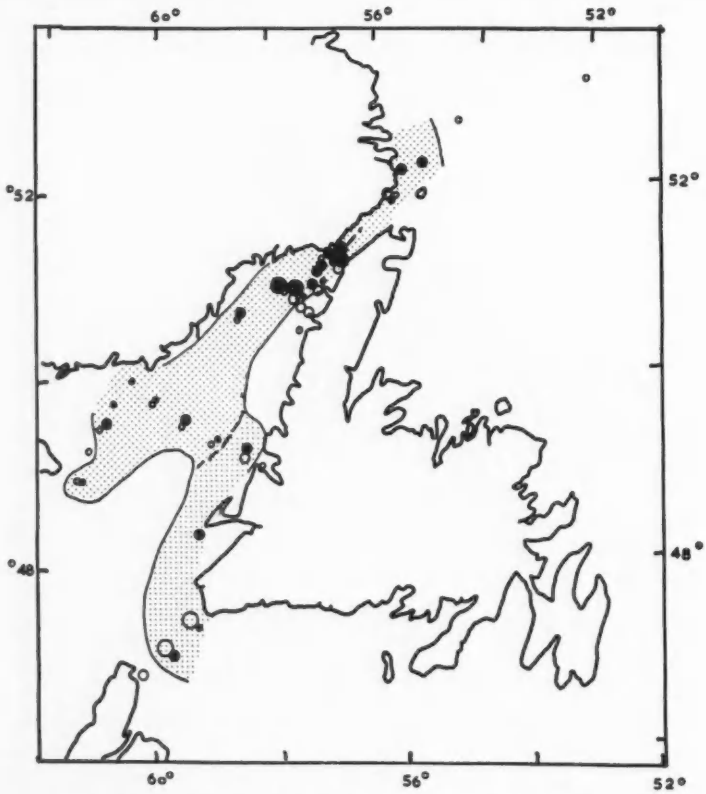

FIGURE 6. Distribution of *Oikopleura vanhöffeni* and *Oi. labradoriensis* in deep plankton hauls of August, 1923. Symbols as in Figure 4, with the sparsely stippled area representing occurrence of *Oi. vanhöffeni* in deep hauls.

from stations 13 to 19 would have been confusing without the results of the shallower hauls.

To summarize the August situation: the water originating wholly or mainly from the inner part of the Labrador current penetrated in through the Strait of Belle Isle and reached the traverse from station 427 to 432 with little mixing. From here down to Anticosti Island the surface layer contained very few specimens of the Arctic *Oi. vanhöffeni*. This species occurred over the whole area in largest amounts at a depth of 20 to 30 m., or even in deeper hauls.

At the same time indications of weak arctic influence extended from Cabot Strait along the Newfoundland coast as far north as the Bay of Islands in the deep water. The surface water of the hauls along Newfoundland up to the Strait of Belle Isle contained only *labradoriensis*.

September Hauls

STRAIT OF BELLE ISLE. For the surface hauls (Fig. 7, 8), the distribution of Arctic and Gulf water as shown by the occurrence of *vanhöffeni* alone, and to-

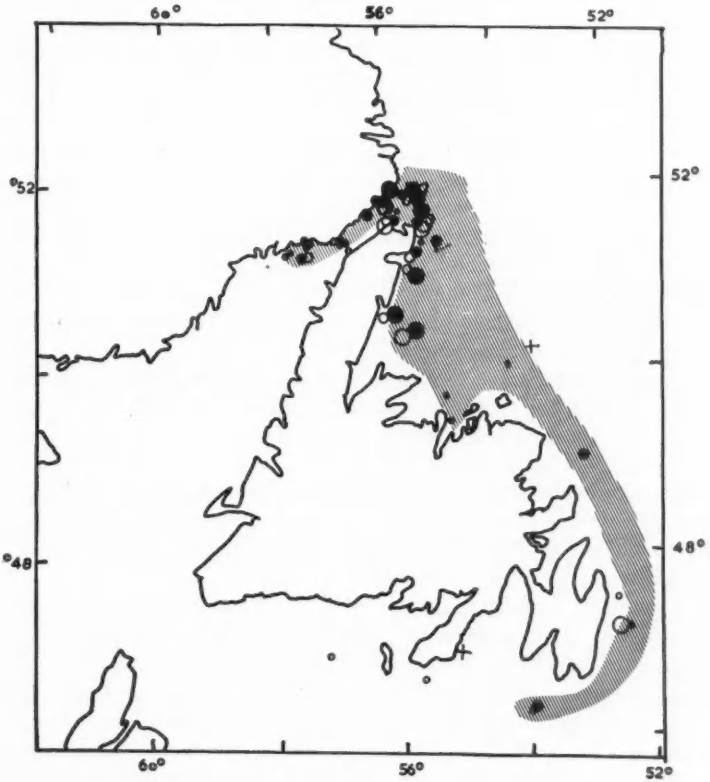

FIGURE 7. Distribution of *Oikopleura vanhöffeni* and *Oi. labradoriensis* in surface plankton hauls of September, 1923. Symbols as in Figure 4.

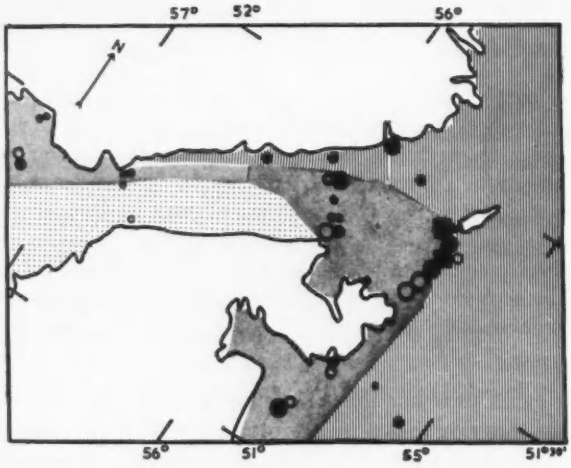

FIGURE 8. Distribution of *Oikopleura vanhöffeni* and *Oi. labradoriensis* in surface plankton hauls in the Strait of Belle Isle in September, 1923. Symbols as in Figure 4, but the lined area represents occurrence of *Oi. vanhöffeni* alone, the finely stippled area that of *Oi. labradoriensis* alone, and the coarsely stippled area that of both species together.

gether with *labradoriensis*, respectively, agrees completely with that of Pinhey's map (1927a, Fig. 8), which was based on the occurrence of the entomostracans *Anomalocera patersoni* and *Temora similis*.

In the traverse between Wreck Bay and Cape Norman (68 to 64) unmixed Arctic water was found only near the surface at the station closest to the Labrador coast (68). Pinhey states that along the southern coast there was pure "Gulf" water, as indicated by the Entomostraca. However, *vanhöffeni* occurs even at the southernmost station (64).

In the September traverse between Amour Point and Savage Cove (412 to 408) in the Strait the surface situation again agrees with that indicated by Pinhey. Arctic influence is evident at the northernmost stations (412, 411), the rest having *labradoriensis* alone.

The appendicularians of three stations at the north end of the Esquiman Channel indicate quite mixed water (448, 449, 451), whereas station 60 close to the Newfoundland coast gave only a few *labradoriensis*, just as found about a month earlier.

At a depth of 20 to 30 m. (Fig. 9, 10) the traverses between Labrador and Belle Isle (68 to 73), and between Belle Isle and Cape Bauld (74–78), indicate the presence of slightly mixed water, the warm-water influence being strongest at station 78, where *labradoriensis* even predominates. Station 68 is here, as well as for the surface hauls, a purely arctic station with *vanhöffeni* only; and station 69 has this species in very large numbers, with only one *labradoriensis* and that at the surface. The Entomostraca of Pinhey, and the surface temperatures of the stations, corroborate this result very well.

Although for August I did not find important amounts of appendicularians at and off the entrance of the Strait, in September *vanhöffeni* occurred in very large numbers along the whole of the two outer traverses. The numbers found for the inner traverse (68–64) emphasize strikingly that *vanhöffeni* belongs to the unmixed "Arctic" water while *labradoriensis* is abundant in the most mixed water. Comparison of the quantities of *vanhöffeni* in this traverse with those of

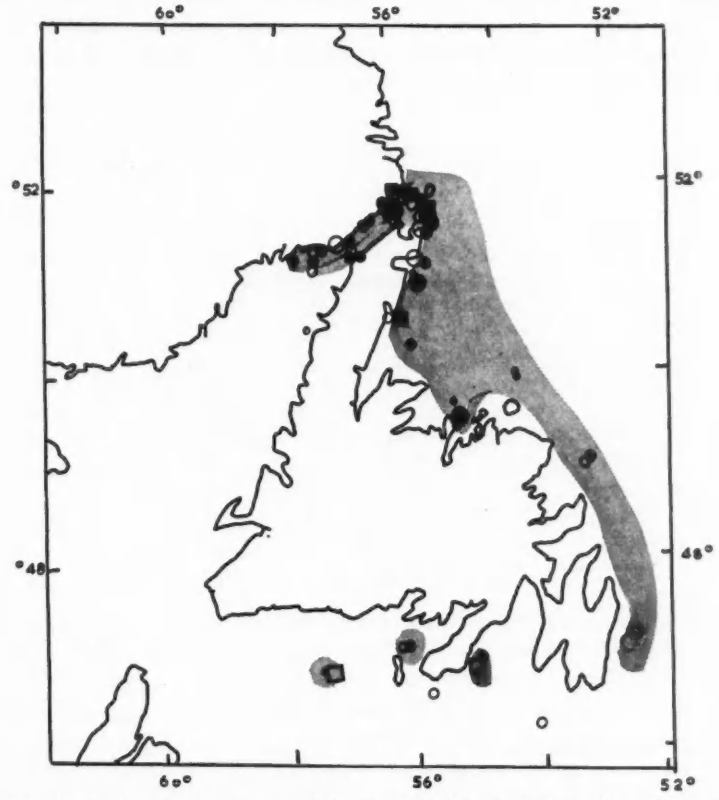

FIGURE 9. Distribution of *Oikopleura vanhöffeni* and *Oi. labradoriensis* in 20- to 30-m. plankton hauls of September, 1923. Symbols as in Figures 4 and 5.

the corresponding part of the outer traverse (69–73), shows a striking decrease in numbers for such a relatively short distance. The quantitative data indicate nothing else than that the water of the Labrador current became mixed with the presumed "Gulf" water. However, closer investigation of *Oi. vanhöffeni* will show that in this first phase of mixing the less resistant planktonic organisms of the current perish quite suddenly.

Essenberg (1926) pointed out that the appendicularians die piecemeal, by means of slow, partial and gradual disintegration, when ecological conditions

become unfavourable. This disintegration starts in the anterior part of the trunk, and, while the mouth parts and the esophagus have already become completely shrunken and the trunk contains no more than the stomach lobes and the genitalia, the tail still moves vigorously, which means that the animal is still partially alive. We might presume that such a partially shrunken animal is still able to maintain its floating posture in the water, within or without its house. Essenberg stated that this disintegration could be brought about by the altered environment when the animal is put into an aquarium or into a small dish of sea water for observation. Thus this disintegration is caused by changes in the water as an ecological medium for the appendicularian.

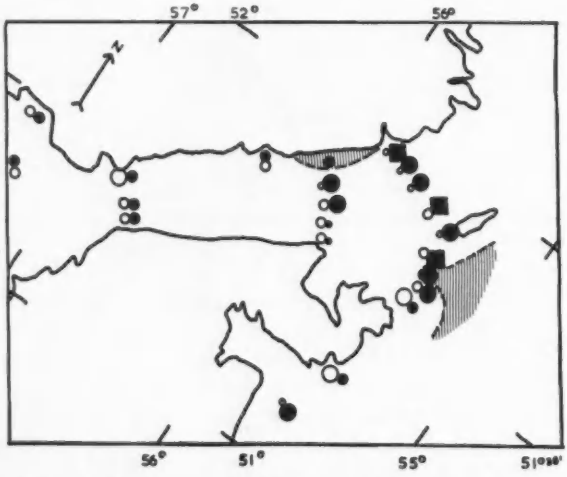

FIGURE 10. Distribution of *Oikopleura vanhöffeni* and *Oi. labradoriensis* in 20- to 30-m. plankton hauls in the Strait of Belle Isle in September, 1923. Symbols as in Figures 4 and 8.

But such partially or completely disintegrated oikopleurids are very common in plankton samples. In the samples of the present investigation containing more than five specimens per haul, there are altogether only two samples containing *vanhöffeni*, and three containing *labradoriensis* that are without damaged specimens.

From the ratio of disintegrating to whole specimens of *vanhöffeni* at the mouth of the Strait of Belle Isle, we have to conclude that the mixing of the Arctic water with that of the Strait must have established quite unfavourable circumstances for *Oi. vanhöffeni* (Table II). In the mixed water of the inner traverse (68–64), 78 per cent of the *vanhöffeni* specimens in surface hauls were disintegrated or disintegrating animals, while their proportion in the outer traverse (68–73) was only 31 per cent. In the cooler water of the 20- to 30-m. hauls, the proportions are 60 per cent for the inner and 20 per cent for the outer traverse.

As no further details on the ecology and resistance of the oikopleurids are

TABLE II. Number and ratio of the whole and disintegrating specimens of *Oikopleura vanhöffeni* at surface and 20- to 30-m. hauls of *Arleux* stations 68–64 (A, inner traverse) and 69–73 (B, outer traverse) in the middle of September, 1923, at Belle Isle Strait. Surface hauls of stations 70 and 72 were not investigated.

Station No.	Surface		20–30 m.	
	Whole	Disint.	Whole	Disint.
A. Inner traverse				
68	52	40	33	19
67	33	252	36	79
66	0	0	72	101
65	0	2	0	2
64	3	22	0	9
Total	88	316	141	210
Percentage		78%		60%
B. Outer traverse				
69	148	158	425	134
70	..	..	158	26
71	24	64	269	87
72	..	..	527	129
73	949	292	191	36
Total	1121	514	1570	412
Percentage		31%		20%

known, we are not able to define what is the particular environmental factor that causes disintegration. A comparison between the proportions of the whole and disintegrating animals in day and night hauls, and with different temperatures and salinities of the water did not show any correlation. This was to be expected since the disintegration evidently started earlier than the time of collecting, at which time conditions might have been different.

20- TO 30-M. HAULS IN THE INNER PART OF THE STRAIT (Fig. 9). These hauls of the traverse of Savage Point (412 to 408), and of the stations at the inner end of the Strait indicate uniform mixing of the water. Both species of *Oikopleura* are fairly scarce at all the stations investigated.

EAST OF NEWFOUNDLAND. South of Belle Isle the Labrador current seems not to follow the coastline of Newfoundland, but to take only a generally southward course. The coastal stations contain a mixed appendicularian fauna, that is, both species of *Oikopleura* are common (82, 83, 84). The western edge of the water of the current is shown by the surface hauls at stations 80 and 81, and the 20- to 30-m. haul of station 85. The main part of the current turns eastward before reaching the archipelago of Notre Dame Bay. However, some pure Arctic water goes inshore since in the Bay of Exploits there are stations with a pure *vanhöffeni* fauna (surface hauls 89, 91, 20–30 m. 91, 125 m. 88). Station 93 in the open sea was without *Oikopleura* and may indicate the eastern edge of the current. Station 94, with only *vanhöffeni* at the surface, is the last trace of the unmixed water of the Labrador current. Mixed water at the surface can be traced farther, as in the

occurrence of both species off Cape St. Mary (97). Below 20 m. (Fig. 9) and in still deeper layers (Fig. 11) the mixed water penetrates about as far as Miquelon Island (102, 103) and very probably it still had in August a connection with the *vanhöffeni* stations of Cabot Strait.

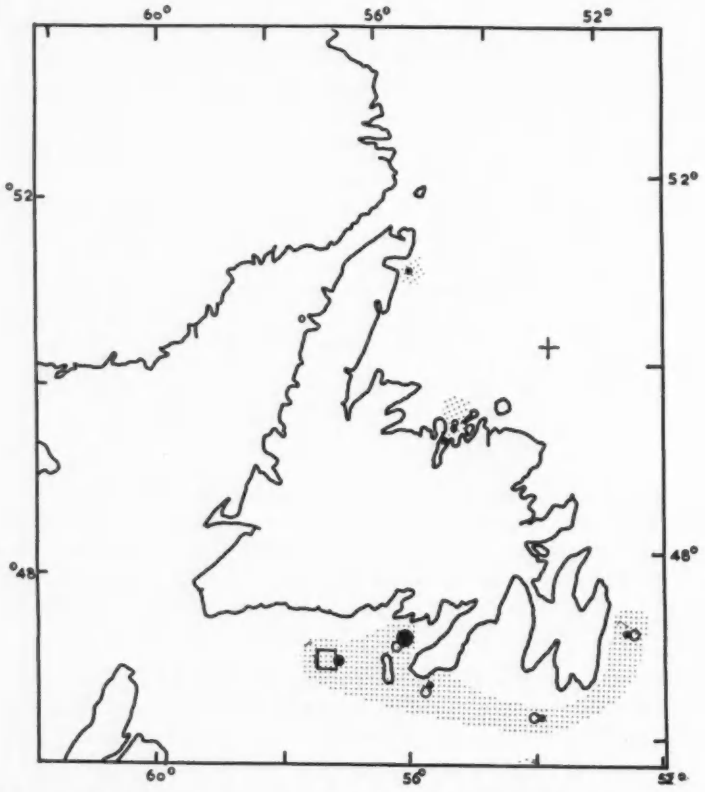

FIGURE 11. Distribution of *Oikopleura vanhöffeni* and *Oi labradoriensis* in deep plankton hauls of September, 1923. Symbols as in Figures 4 and 6.

FRITILLARIA

The distribution of *Fritillaria borealis* (Figure 3) gives no clear picture. This species because of its smallness easily eludes discovery when plankton material is sorted. Thus in the already-sorted material I usually found only a few specimens attached to the larger oikopleurids.

I went through the whole surface plankton samples of most of the stations in Cabot Strait and Esquiman Channel, but did not find any *Fritillaria* west of Ferolle Pt. However, Pinhey found it at the stations closest to Cape Whittle, Quebec, and here it even occurs at 20 to 30 m. depth. Pinhey even found it in

the whole breadth of the traverse off the Labrador coast (45, 40, 52). East of Newfoundland it occurred only at the surface as far as Cape St. John, but in the 7-m. hauls of Pinhey as far down as Bonavista Bay. In general, the surface occurrence seems to be coordinated with the most important areas of distribution of *Oi. vanhöffeni*. According to Thompson (1936) this species is indeed an indicator of water of partially arctic origin, but its tolerance toward higher temperatures is greater.

Occurence of Disintegrated and Juvenile Oi. vanhöffeni

Thompson and Frost (1936) showed, mainly from the distribution of *Oi. vanhöffeni*, that the Labrador current differs in strength from year to year. In years with heavy flow, for example, in 1933 and 1935, the main branch passing down along the east coast of Newfoundland does not disappear at the eastern edge of St. Pierre bank, but is continued along the southern coast of Newfound-

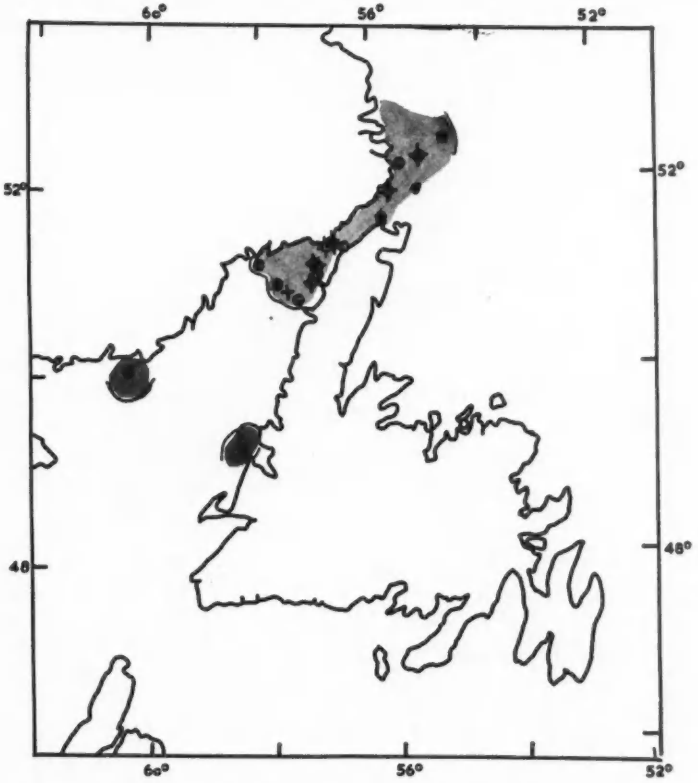

Figure 12. Distribution of hauls with more whole than disintegrating specimens of *Oikopleura vanhöffeni* as taken in August, 1923. Solid circles indicate surface hauls, open circles 20- to 30-metre hauls, and crosses deep hauls. Stippling as in Figures 4–6.

land into Cabot Strait and up into the Esquiman Channel. They indicated differences in the extent of the penetration of the current into the Gulf through the Strait of Belle Isle, but they are handicapped by having information only from the Newfoundland side of the Esquiman Channel. Mr. W. B. Bailey and Dr. H. B. Hachey have studied the hydrographic data obtained in 1923 and conclude (Huntsman, Bailey and Hachey, 1954) that just before the first survey of the Strait was made there had been a dominant flow of water inward bearing icebergs from the Labrador current. During the survey, there was progressive movement inward along the north shore and outward along the south shore with a dominant flow outward. In the Esquiman Channel the water was circulating in two contraclockwise eddies, one north and the other south of the Mekattina bank, which stretches obliquely across the channel from station 23 to station 28.

If we try to compare the appendicularian hauls with the current situation as postulated on the basis of Thompson and Frost's considerations and as found by Bailey and Hachey, we find that in the late summer of 1923 the large number

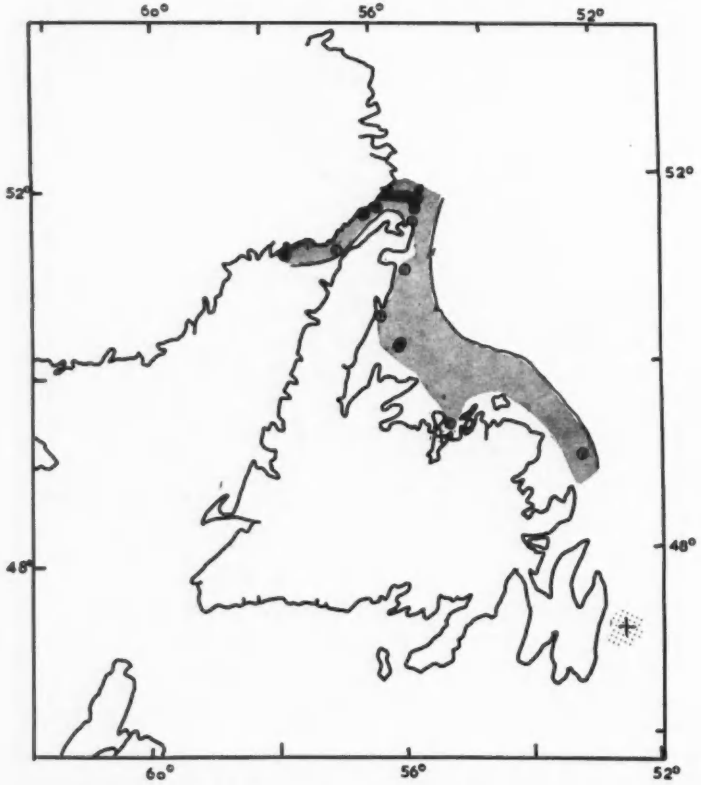

FIGURE 13. Distribution of hauls with more whole than disintegrating specimens of *Oikopleura vanhöffeni* as taken in September, 1923. Symbols as in Figure 12.

of *vanhöffeni* stations indicates a strong arctic current penetrating the Gulf of St. Lawrence when or before the hauls were taken.

Thompson and Frost based their presumed course for the current mainly on stations containing only *vanhöffeni*, as can be seen on their distribution charts (Frost *et al.*, 1933, 1934). Such stations in 1923 were quite few, omitting hauls containing less than 10 oikopleurids. Therefore, I have had to look for some other way of analysing further the distributional data of the oikopleurids. I tried to use for this purpose the ratio between undamaged and disintegrating specimens of *vanhöffeni*. As we have seen earlier, the disintegration of the *vanhöffeni* specimens was considerable where the first mixture of the Labrador current took place. Among all the 106 *vanhöffeni* hauls (containing more than 10 specimens) only 46 had undamaged specimens in a majority. I plotted these hauls on a chart for August (Fig. 12) and found that the area covered by the surface stations of this kind correspond fairly well with that of the pure *vanhöffeni* stations and with those having an abundance of large *vanhöffeni*. Further, they may indicate that the mixture of Arctic and Gulf water, in the eddy north of Mekattina bank

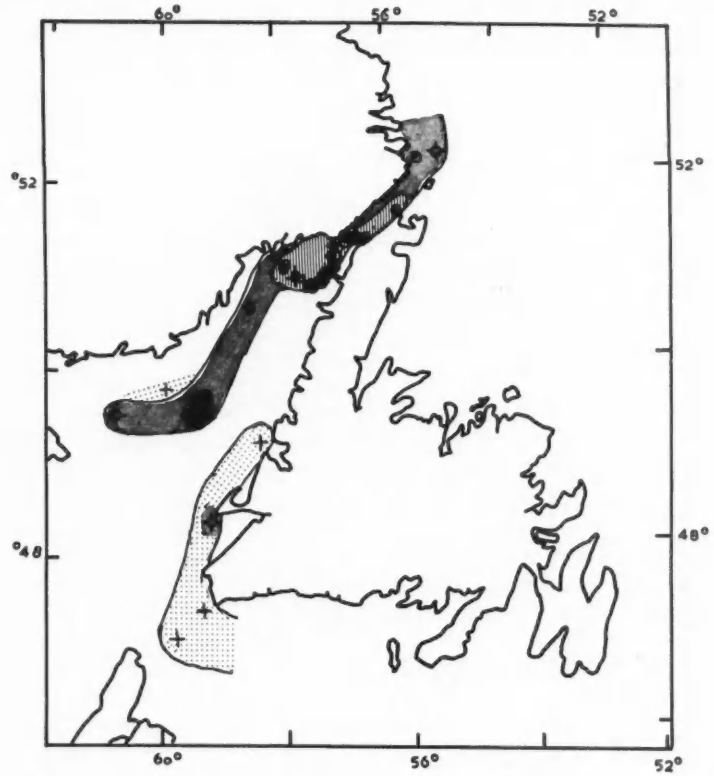

FIGURE 14. Distribution of immature (juvenile) specimens of *Oikopleura vanhöffeni* in August, 1923. Symbols as in Figure 12.

and in the outflow through the strait, was not yet complete, and therefore not yet unfavourable for Arctic forms like *Oi. vanhöffeni*.

The stations of the 20- to 30-m. hauls in September (Fig. 13) in addition extend the distribution in the main direction of the current according to Thompson and Frost.

Table III shows that the rate of disintegration was generally higher with *vanhöffeni* than with *labradoriensis*. The latter species seems to be more euryecious, that is, tolerant of a wider range of environmental conditions.

TABLE III. Percentage of number of stations containing more whole than disintegrating specimens of *Oi. vanhöffeni* and *Oi. labradoriensis*.

	vanhöffeni	*labradoriensis*
Surface hauls	27.8%	42.1%
20- to 30-m. hauls	56.0	65.7
Deeper hauls	42.9	64.7

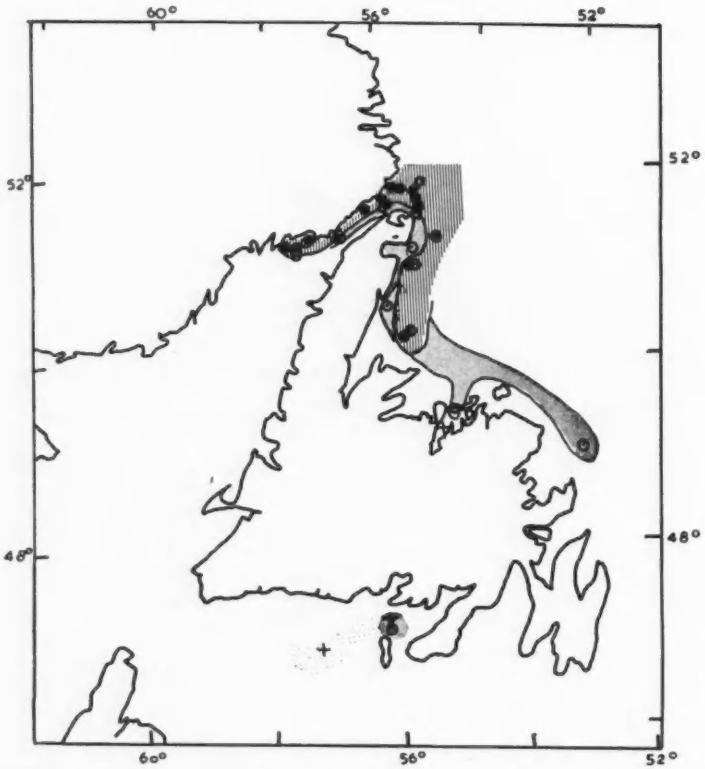

FIGURE 15. Distribution of immature (juvenile) specimens of *Oikopleura vanhöffeni* in September, 1923. Symbols as in Figure 12.

I made a further analysis of the *vanhöffeni* material. While the hauls where it is abundant almost always contain both mature or adult specimens, and semi-adult or immature animals, the occurrence of juvenile forms (without developed genital organs) is restricted to some stations. The distribution of these stations (Fig. 14, 15) is generally the same as the distribution of the stations with whole *vanhöffeni* specimens in a majority. Although reproduction sometimes happens very far from the optimum ecological conditions, this is seemingly not the case for *Oi. vanhöffeni*. The coincidence of lack of juvenile forms with the high ratio of disintegration in mature ones indicates that at those stations some controlling factor or factors were effective; the ultimate factor, very probably, is the mixing of Arctic water with that of more southern origin. Future analysis may further elucidate the conditions favourable and unfavourable to *Oi. vanhöffeni* throughout the area of investigation.

CONCLUSIONS

In 1923 in the waters around Newfoundland the influence of the strong Labrador current predominated.

(*a*) North of Belle Isle, in the latitude of Double Island, the current was unmixed in its inner half, as it contained only *Oi. vanhöffeni*, while its outer half contained only *Oi. labradoriensis*.

(*b*) The influence of the unmixed, or only less mixed current could be followed in August through the Strait of Belle Isle down to the traverse between Shekatika Bay and Rich Point. Both on the surface and in 20- to 30-m. hauls the current is indicated partly by pure *vanhöffeni* hauls, partly by the great abundance of *vanhöffeni* as well as by the occurrence of its juvenile form or by the dominance of whole specimens over disintegrating or disintegrated animals. The presumed course of the current is shown in Figures 4, 5, 6, 14 and 15.

(*c*) Close to the west coast of Newfoundland there are signs of arctic influence extending inward from Cabot Strait, but not reaching the surface layer.

(*d*) In September the Labrador current was slightly mixed even near Belle Isle. The course of the current indicated by the *Oikopleura* species is shown in the figures, and the results agree with those of Pinhey which were based on entomostracan material. At the outer end of the Strait the degree of mixing is strikingly shown by the proportions of the two oikopleurids as well as by the amount of disintegration of *Oi. vanhöffeni*.

(*e*) The main flow of the Labrador current, east of Newfoundland, can be followed down to Bonavista Bay, the occurrence of juveniles and the ratio of disintegration of *Oi. vanhöffeni* again helps to establish the distribution of the unmixed and mixed Arctic water.

(*f*) Off the south shore of Newfoundland there were some traces of arctic influence in hauls deeper than 20 m. This mixed water presumably was connected at least in August with similar water mentioned under (*c*).

(*g*) These conclusions correspond to those of Pinhey. The description of the presumed course of the Labrador current corresponds mainly with the chart of Thompson and Frost, based on the distribution of the same oikopleurids during

several years in the 1930's. The hydrographic data of the Belle Isle Strait and Esquiman Channel as interpreted by Huntsman *et al.* correspond to the distribution of the oikopleurids. In general, if we consider not only the occurrence of *Oi. vanhöffeni*, but also the proportion of juvenile forms and of undamaged specimens, we might conclude that the Labrador current is mainly mixed in the latitude of Newfoundland, and more characteristic forms like *Oi. vanhöffeni* easily perish, or fail to reproduce in the mixed water.

(*h*) *Oi. labradoriensis* occurred in the area in water of warmer origin, or in the water of the Labrador current where it was diluted with more southern water. *Fritillaria borealis* occurred over the whole area, most sparsely in the southern parts. It was only found in surface hauls where arctic and other water primarily became mixed. *Oi. dioica* was totally lacking, indicating by its absence that there was very little if any southern influence from the area of the Banks in this year.

ACKNOWLEDGMENTS

Grateful acknowledgment is made to Dr. A. G. Huntsman, who initiated this present investigation and who furnished me with much aid and advice during the preparation of the paper. I am indebted to Dr. W. A. Clemens and Dr. J. R. Dymond, Dr. F. E. J. Fry and Dr. J. L. Hart, who kindly allowed me to work on this material in their institutions.

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APPENDIX

TABLE I. Appendicularians found in plankton samples from the Strait of Belle Isle. Entries in colums 3 and 6 include both adult and juvenile individuals. Presence of juveniles is indicated by a cross in columns 4 and 7. If a majority of adult and juvenile specimens were whole (i.e., not disintegrating) this is indicated by a cross in columns 5 and 8. Indeterminable *Oikopleura*, that is, either damaged specimens of *vanhöffeni* and *labradoriensis*, or other species, are entered in column 9. An asterisk (*) indicates that the whole sample was examined by the writer; other samples had been sorted earlier.

A. SURFACE HAULS

1	2	3	4	5	6	7	8	9	10
		Oi. vanhöffeni			*Oi. labradoriensis*				
Station	Date 1923	No.	Juveniles	Maj. whole	No.	Juveniles	Maj. whole	*Oikopleura* sp.	*Fritillaria borealis*
2*	Aug. 7				65	+	+	–	–
3	"				280	–	–	–	–
9*	Aug. 11				6	+	–	–	–
14	"	1	+	–	1	–	+	–	–
17*	Aug. 12	5	–	+				–	–
18	"				2	–	+	–	–
19*	"				137	+	–	–	–
23	Aug. 15	1	–	–	12	+	+	–	–
26	"	2	+	–	2	–	–	–	–
28*	Aug. 16	19	+	–	5	–	–	–	–
30*	"	62	+	–	1	–	–	–	1
32	"	2	+	–	9	–	–	–	–
33	"	302	+	+				–	–
35	"	31	+	–	4	–	–	–	–
37*	Aug. 17	67	+	–	2	–	–	–	–
43*	"	829	+	–	199	+	–	–	–
44*	"	6	–	+				–	–
45*	Aug. 18	8	–	–				–	–
46	"	5	–	–				–	–
47*	"	16	–	+				–	–
54	Aug. 21	43	+	–	42	+	+	–	–
55	"				7	–	–	–	–
57	"	103	+	–	6	–	+	–	–
64	Sept. 6	25	–	–	223	+	–	–	–
65	"	2	–	–	1	–	–	–	–
66	"				5	–	–	–	–
67	"	286	+	–	15	–	+	–	1
68	"	92	+	+				–	–
69	Sept. 7	323	+	–				–	7
71	"	88	+	–				–	1
73*	"	1,283	+	+	1	–	+	–	380
74*	"	218	+	+				–	20
75*	"	2,953	+	+	45	+	+	44	146
76	"	280	+	–				–	–
77	"	83	+	–	381	+	+	–	–
78	"	30	–	–	171	–	–	–	–

TABLE I—*Continued.*

A. SURFACE HAULS—*Continued*

1	2	3	4	5	6	7	8	9	10
		Oi. vanhöffeni			*Oi. labradoriensis*				
Station	Date 1923	No.	Juveniles	Maj. whole	No.	Juveniles	Maj. whole	*Oikopleura* sp.	*Fritillaria borealis*
80	Sept. 9	43	+	−				−	1
81	"	3	−	+				−	−
82	Sept. 11	15	−	−	12	−	+	−	−
83	"	206	+	−	20	+	+	−	2
84	"	130	−	−	59	−	+	−	−
85*	"	352	+	+	313	+	+	2	42
89	Sept. 12	1	−	−				−	−
91	Sept. 14	5	−	+				−	−
92	"	9	−	−				−	−
94	Sept. 15	32	−	−				−	−
95*	Sept. 18				1	−	−	−	−
96	"	10	−	−	174	−	−	3	−
97*	Sept. 19	34	−	−	2	−	−	1	−
101*	Sept. 20				1	−	+	−	−
103	Sept. 21				1	−	−	−	−
408*	Aug. 7	49	+	−	47	+	−	10	2
409	"	48	+	−	5	−	+	14	−
410*	"	11	+	−	15	+	−	−	−
411*	"	35	−	−				−	−
412	"	55	−	−				−	−
408	Sept. 7				4	−	−	−	−
409*	"							−	9
411	"				3	−	−	−	−
412	"	9	+	−	1	−	−	−	52
427*	July 30				9	+	−	−	−
429	July 31				7	−	−	−	−
430*	"	79	+	+	4	−	−	4	−
431*	"	13	+	−	65	+	−	−	−
432	Aug. 2	1	−	−				−	−
447	Sept. 6	17	+	+				−	−
448	Sept. 10	4	+	+	1	−	−	−	−
449	Sept. 13	3	+	+	2	+	+	−	−
451	Sept. 15	25	+	−	55	+	−	−	1
Sum of specimens		8,354			2,423			78	663
Sum of stations		54	33	15	47	17	16	7	14

B. 20- to 30-m. HAULS

2	Aug. 7				32	−	−	−	−
3	"	4	−	−	134	+	−	−	−
6	Aug. 10	102	+	−	174	+	−	−	−
11	Aug. 11				1	−	−	−	−
12	"				3	−	+	−	−

TABLE I—*Continued.*

B. 20- to 30-m. HAULS—*Continued*

1	2	3	4	5	6	7	8	9	10
		Oi. vanhöffeni			*Oi. labradoriensis*				
Station	Date 1923	No.	Juveniles	Maj. whole	No.	Juveniles	Maj. whole	*Oikopleura* sp.	*Fritillaria borealis*
13	"	175	+	−	5	−	+	1	−
15	Aug. 12	47	−	+				−	3
16	"	47	−	−	1	−	+	−	−
17	"	132	+	−	8	−	+	−	−
18	"				1	−	+	−	−
19	"	70	−	+	333	+	+	−	1
23	Aug. 15	869	+	−	29	−	+	−	1
26	Aug. 16	17	+	−	44	+	−	−	−
28	"	165	+	−	24	+	+	−	1
30	"	92	+	+	20	+	+	−	1
32*	"	20	+	−	114	+	−	−	−
33*	"	331	+	+	12	+	−	4	2
35*	"	24	+	+	1	−	−	−	−
37	Aug. 17	71	+	+				−	−
43	"	106	+	+	30	+	+	−	−
45	Aug. 18	11	+	+				−	−
46	"	34	+	−				−	−
47	"	1	−	−				−	−
52	Aug. 19				3	−	+	−	−
59	Aug. 30				2	+	−	−	−
60	Sept. 1				5	−	−	−	−
64	Sept. 6	10	−	−	65	−	−	−	−
65	"	4	−	−	33	−	−	4	−
66	"	178	+	−	47	+	+	−	−
67	"	115	−	−	7	−	+	−	−
68	"	52	−	+				−	−
69	Sept. 7	589	+	+	1	−	+	−	−
70	"	158	+	+	1	−	+	−	−
71	"	367	+	+	2	−	+	−	−
72	"	701	+	+	29	+	+	−	−
73	"	243	+	+	5	−	+	−	−
75	"	673	+	+	20	+	+	−	−
76	"	117	+	+				−	−
77	"	258	−	−	32	−	−	−	−
78	"	40	+	+	109	+	+	−	−
82	Sept. 11	77	+	−	147	−	+	−	−
83	"	175	+	+	7	−	+	−	−
84	"	528	+	+	64	−	+	−	−
85	"	72	+	+				−	−
89	Sept. 12	142	+	+	4	+	+	−	−
91	Sept. 14	3	−	+				−	−
92	"	3	−	+	2	+	+	−	−
94	Sept. 15	21	+	+	16	−	+	−	−
96	Sept. 18	182	−	−	326	+	−	3	−

TABLE I—*Continued.*

B. 20- to 30-m. HAULS—*Continued*

1	2	3	4	5	6	7	8	9	10
		Oi. vanhöffeni			*Oi. labradoriensis*				
Station	Date 1923	No.	Juveniles	Maj. whole	No.	Juveniles	Maj. whole	*Oikopleura* sp.	*Fritillaria borealis*
97	Sept. 19				64	–	–	–	–
100	Sept. 20	13	–	–	769	+	+	–	–
101	"				88	–	–	–	–
102*	"	53	+	–	71	+	–	–	–
105	Sept. 21	7	–	–	634	+	–	–	–
409	Aug. 7	746	+	–	60	–	+	14	–
411	"	405	+	+		–			1
412	"	84	+	+	7	–	+	–	–
409	Sept. 7	200–300	–	–	?	–	–	?	?
410	"	34	+	+	77	+	+	–	1
412	"	73	+	–	403	+	+	–	–
426	Aug. 16	11	–	+				2	1
427	July 30				408	+	+	–	–
428	July 31	29	–	+	395	–	+	–	–
429	"	11	–	–	35	+	+	–	–
431	"	370	+	–	2	+	+	–	–
432	Aug. 2	240	+	+	1	+	+	–	7
439	Aug. 17				24	+	+	–	–
448	Sept. 10	21	–	–	14	–	+	–	–
449	Sept. 13	12	–	+	1	–	–	–	–
451	Sept. 15	74	+	–	31	+	+	23	–
Sum of specimens		9,509			4,977			51	19
Sum of stations		59	38	31	58	28	39	7	10

C. DEEP AND VERTICAL HAULS

1	1*a*	2	3	4	5	6	7	8	9	10
			Oi. vanhöffeni			*Oi. labradoriensis*				
Station	Depth	Date 1923	No.	Juveniles	Maj. whole	No.	Juveniles	Maj. whole	*Oikopleura* sp.	*Fritillaria borealis*
1	140–0	Aug. 7				63	–	–	–	–
2	400–0	"	13	+	–	212	+	–	–	–
3	150–0	"	7	+	+	104	+	–	7	–
6	100–0	Aug. 10	68	+	–			–	–	–
11	75–0	Aug. 11	2	–	–	1	+	+	–	–
12	150–0	"		–		1	–	+	–	–
13	280–0	"	14	+	–	4	–	–	–	–
14	150–0	"	6	–	+				–	–
15	100–0	Aug. 12	1	–	+				–	–
16	90–0	"	6	+	+	1	–	+	–	–

TABLE I—*Continued.*

C. DEEP AND VERTICAL HAULS—*Continued*

1	1a	2	3	4	5	6	7	8	9	10
			Oi. vanhöffeni			*Oi. labradoriensis*				
Station	Depth	Date 1923	No.	Juveniles	Maj. whole	No.	Juveniles	Maj. whole	*Oikopleura* sp.	*Fritillaria borealis*
17	260–0	Aug. 12	11	–	–	5	–	–	6	–
18	150–0	"	1	–	–	1	+	+	–	–
19	60–0	"	26	+	–	55	+	–	–	2
23	230–0	Aug. 15	21	–	–	4	–	+	–	–
26	80–0	Aug. 16	3	–	–	10	–	+	–	–
30	50–0	"	60	+	+	22	+	+	–	–
32	62–0	"	2	–	+				–	–
33	85–0	"	46	–	+				–	–
35	63–0	"	79	+	+	4	+	+	–	–
37	100–0	Aug. 17	33	+	+				–	–
39	50–0	"	46	+	–				–	–
45	150–0	Aug. 18	28	–	–				–	–
46	150–0	"	66	+	+				–	–
48	175–0	"				1	–	+	–	–
52	350–0	Aug. 19				10	–	–	–	–
59	200–150	Aug. 30				8	+	–	–	–
59	275–0	Aug. 30				3	–	–	–	–
60	250–0	Sept. 1				3	–	–	–	–
83	190–0	Sept. 11	1	–	+				–	–
88	125–0	Sept. 12	48	+	+				–	–
89	300–0	"	4	–	–	1	–	+	–	–
96	150–0	Sept. 18	9	–	+	21	+	+	21	–
97	150–0	Sept. 19	1	–	–	19	–	–	–	–
101	150–0	Sept. 20	1	–	+	28	+	+	–	–
102	200–0	"	106	+	–	35	–	+	–	–
103	130–0	Sept. 21	18	+	–	598	+	+	–	–
410	90–0	Aug. 7	688	+	+	45	–	+	–	–
411	55 vert.	"	128	+	–				–	–
426	45 "	Aug. 16	10	–	+	2	–	+	2	1
427	180 "	July 30				13	+	+	–	–
428	65 "	July 31				67	+	+	–	–
429	75 "	"	166	+	+	63	+	+	–	1
430	100 "	"	432	+	–	9	–	–	–	–
439	75 "	Aug. 17				18	–	+	–	–
Sum of specimens			2,151			1,431			36	4
Sum of stations			34	18	17	32	14	20	4	3

Additions to the Polychaete Fauna of Canada, with Comments on Some Older Records[1]

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ABSTRACT

Descriptions are given of the new genera *Neopygospio* (type *N. laminifera*, nov.) and *Novobranchus* (type *N. pacificus*, nov.); of the new species *Nereis* (*Eunereis*) *wailesi*, *Spio butleri*, *Neopygospio laminifera*, *Novobranchus pacificus*; and of the new variety *pacificus* of *Distylia volutacornis* (Montagu). All are from the Pacific coast of Canada. Synonymy is proposed of *Lepidonotus caelorus* Moore with *L. squamatus* (Linné), and of *Goniada eximia* Ehlers with *Ophioglycera gigantea* Verrill. In addition to the new species and variety, records of three species new to western Canada are presented, and notes on others. Thirteen species and a variety new to eastern Canada are recorded, one of them new to North America.

INTRODUCTION

In papers published in 1948 and 1952 we summarized the records of Polychaeta known from the west coast of Canada up to those years. We have since had opportunity to examine old material deposited in the museum of the Pacific Biological Station which had not been through our hands previously, as well as more recent collections made both by members of the station staff and by ourselves. The present paper contains an account of such points of interest as have arisen as a result of this work. Two new genera, with their type-species, two other new species, and a new variety are described from the west coast.

The paper also includes records of species new to the east coast of Canada and notes on others previously recorded from that coast. The majority of these have been derived from material collected from the coast of Nova Scotia during the summer of 1953 by Mr. W. L. Klawe, a student assistant at the Atlantic Biological Station, who kindly submitted them to us for examination. All the records from Nova Scotia in the following pages are due to Mr. Klawe unless otherwise specified. Thirteen species and one variety new to eastern Canada are recorded. Amongst the 13 species six have been reported previously from western Canada or Hudson Bay (or from both of these localities), six are new to both coasts of Canada, but known from the eastern United States, and one is entirely new to North America.

Very little systematic collecting of polychaetes from the east coast of Canada has been done during recent years. Treadwell (1948) summarizes the majority of records up to that year. Most of these are derived from the early works of Whiteaves (1901), McIntosh (1874 to 1916) and Verrill (1874 to 1885), the

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most recent being those of Baillie (1946) from material collected in the Bay of Fundy in 1911–12. It is interesting to find that careful collecting, such as that conducted by Mr. Klawe, can make further contributions.

Polynoidae

Lepidonotus squamatus (Linné)

Aphrodita squamata Linné, 1766, Syst. Nat., 12th ed., p. 1084.
Lepidonotus squamatus McIntosh, 1900, p. 274; Fauvel, 1923, p. 45.
Lepidonotus caelorus Moore, 1903, p. 412; 1905, p. 546; 1908, p. 331; 1910, p. 333. Berkeley, 1923, p. 213; E. and C. Berkeley, 1941, p. 20; 1942, p. 187; 1948, p. 9. **New Synonymy.**

A collection of Polychaeta from Rose Harbour, Queen Charlotte Islands, made in 1935 (collector unknown), was found to contain several specimens agreeing exactly with the descriptions of this species. This led us to re-examine the many representatives of the genus *Lepidonotus* collected off the coast of British Columbia, from California, and from Alaska, which we have recorded in the past as *L. caelorus* Moore.

Johnson (1901, p. 386) recorded the present species as *Polynoe squamata* (L.) from the Puget Sound area and from California and suggested that it would be found to have as wide a distribution on both sides of the Northern Pacific as it was already known to have on both sides of the North Atlantic. Izuka (1912, p. 12) supported this suggestion by records from numerous stations off the coast of Japan.

L. caelorus Moore was first described from Japan (Moore, 1903, p. 412) and subsequently recorded by the same author (1905, p. 546; 1908, p. 331) as widespread in the Northern Pacific from Alaska to Vancouver. In 1910 (1910, p. 333) he found that it was common off the coast of California and it has since been repeatedly noted in collections from that region and has generally been regarded as the Pacific counterpart of the Atlantic *L. squamatus* (L.).

Commenting on the similarity of the latter species with his *L. caelorus*, Moore (1905 and 1908) specified several alleged differences between the two, in particular with regard to details of the elytra and of the neurosetae. We have found, however, on reviewing our collections, recorded as *L. caelorus* Moore, from British Columbia, from Alaska, and from California, that all the points of difference specified are present in varying degree in individual specimens and that no clear lines of demarcation could be drawn between the two species on the basis of these or any other morphological characters. Doubt being thus raised as to the validity of the differentiation, some Atlantic specimens of *L. squamatus* (L.) were obtained for comparison. Specimens from St. Andrews, New Brunswick, and others from St. Vaast La Hougue, northern France (obtained through the kindness of Mr. Tebble of the British Museum), agreed exactly with some from this coast.

We therefore conclude that *L. caelorus* Moore is a synonym of *L. squamatus* (L.) and that such small differences as occur in certain specimens are individual. Chamberlin (1919, p. 252) suggested that specimens identified by Treadwell (1914, p. 181) and by Johnson (1897, p. 166) from California as *L. squamatus*

(L.) should be included in *L. caelorus* Moore. Treadwell (1937, p. 141) concludes that, if this suggestion be correct, *L. squamatus* (L.) has not been found off the Pacific coast. It would seem, however, that since the latter is the older name, it should stand, and *L. caelorus* Moore go into synonymy.

SIGALIONIDAE

Pholoë tuberculata Southern

Southern, 1914, p. 57.

We recorded this species from the Nanaimo region in 1945 (E. and C. Berkeley, 1945, p. 323). It has since been found in collections from Rose Harbour, Queen Charlotte Islands, and from Blair Island, Queen Charlotte Sound. It is included here in order to record the very large size of the specimens taken at the latter locality. As described by Southern, and in our own previous experience, the species has not exceeded 21 mm. in length, with 68 setigerous segments and 56 pairs of elytra. The specimens from Blair Island reach a length of 40 mm. and have up to 78 setigerous segments and 65 pairs of elytra. They differ in no other respect from the species as previously described. They were collected by Dr. K. S. Ketchen in a very sheltered area.

NEREIDAE

Nereis (*Eunereis*) **wailesi**, sp. n.

A single atokous ripe female, 80 mm. long, 3 mm. wide at the widest point, and consisting of 125 setigers, has the arrangement of the paragnaths peculiar to *Eunereis*. The prostomium is a little longer than wide, the base squared, and the

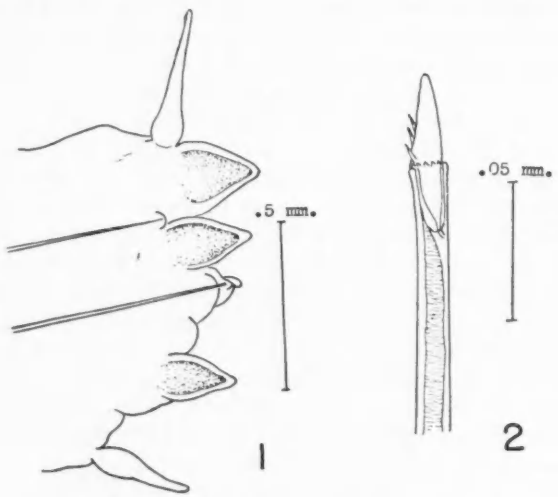

FIGURE 1. *Eunereis wailesi* sp. n. Parapodium (setae omitted).
FIGURE 2. *Eunereis wailesi* sp. n. Specialized notoseta.

eyes large and dark. The palps are normal and reach to the end of the tentacles. The peristomium is twice as long as the following segments, and the tentacular cirri are all short, just reaching the first setiger. The jaws are brown and have four or five small teeth below the main fang. There are no paragnaths on the maxillary ring of the proboscis. On the oral ring the paragnaths are inconspicuous; two on the ventral side are fairly well defined (Group VII); a smaller one lateral to these, and possibly two dorsally, are difficult to make out.

The parapodia differ little throughout the body and have the typical nereid form. The ventral notopodial lobe is somewhat shorter than the dorsal and the same length as the neuropodial. All the lobes are darkly pigmented (Figure 1). The notosetae in the anterior region are all homogomph spinigers. These are gradually replaced by specialized heavy homogomph falcigers with spinous end-pieces (Figure 2) until, terminally, nothing but one or two of the latter remain. The neurosetae consist of a mixture of homogomph spinigers and heterogomph falcigers on the dorsal side and heterogomph falcigers and heterogomph spinigers on the ventral side. No colour remains in the specimen excepting the darkened areas of the parapodial lobes.

N. (*Eunereis*) *wailesi* comes near to *N.* (*Eunereis*) *tridentata* (Webster), differing from the original description of that species (Webster, 1886), mainly in size, in the presence of specialized homogomph notosetae, and in the darkened parapodial lobes.

Collected in 1928 at Cachalot, west coast Vancouver Island, by the late Mr. G. H. Wailes, after whom we take pleasure in naming the species.

(?) *Nereis rubicunda* Ehlers

Ehlers, 1868, p. 529.

We attribute several small Nereids, from mud-flats at Wedgeport, Yarmouth, N.S., to this species with some hesitation. The largest is about 30 mm. long and 2 mm. wide over the parapodia as preserved and has 86 segments; most of the remainder are considerably smaller. They agree in all particulars except size and the proboscideal paragnaths with the much larger species *N. irrorata* (Malmgren). In both the latter particulars they are nearer to *N. rubicunda* Ehlers, which Fauvel (1923) regards as no more than a variety of *N. irrorata*. However, the details of the paragnath arrangement are not quite in accord with those he gives (1914) for *N. rubicunda*. In one of the present specimens Group I is represented by a single paragnath and in all we have been able to examine Group VI is represented by a single one on either side. *N. rubicunda* is known only from the Mediterranean area, whereas *N. irrorata* occurs in northern and Arctic seas. In spite of the rather wide difference in pattern of paragnaths, we would have been inclined to regard the specimens in question as young forms of *N. irrorata* but for the fact that no larger representatives have been taken from the Wedgeport mud-flats in spite of somewhat extensive collecting in that area. Neither *N. rubicunda* nor *N. irrorata* has previously been known from North America.

Nereis succinea (Leuckart)

Fauvel, 1923, p. 346.

This species was not known to occur in Canadian waters until we recorded its swarming in enormous numbers in Miramichi Bay, N.B., in a letter to *Nature* published in May, 1953. We mention this here by way of confirmation. The atokous form of the species has not yet been recorded from Canada.

Nereis virens (Sars)

Fauvel, 1923, p. 348.

Several large specimens of this species taken intertidally at St. Andrews, N.B. and at both Kingsport and Wedgeport, N.S., present a problem in classification. The species is usually placed in the sub-genus *Neanthes*, defining that sub-genus in the same sense as that used by Kinberg (1865), in his original use of the term, as having the paragnaths hard and discrete and every group represented. The number of paragnaths in each group may vary widely between species and in *N. virens* it is well recognized that there is considerable variation in this respect between individuals (Izuka, 1912; Turnbull, 1875). In the specimens in question here Group V of the paragnaths is usually absent and the remaining groups are all represented though the number in each group is small. Turnbull (1875) found Group V absent in four out of six specimens from the Atlantic coast of North America which he examined, but he was not concerned with the sub-generic classification of the species and regarded the absence as being within normal variation. Nowadays it is commonly looked upon as characteristic of the sub-genus *Nereis* (*sensu str.*). Since the specimens under discussion are identical with *N. virens* in every other respect it seems undesirable to separate them on the basis of this character, particularly since in one collection (that from Wedgeport) specimens both with and without Group V occur together. It seems that this character cannot be used as a basis of separation of sub-genera.

Hartman (1940) avoids the difficulty by defining *Neanthes* on the basis of parapodial characters and regards the presence or absence of Group V of the paragnaths as nonessential. This use of an old term in a new sense is confusing and, moreover, the new definition would not resolve the difficulty in the present instance. We are, therefore, using the name *Nereis virens* indiscriminately to cover specimens both with and without Group V of the paragnaths. The species is recorded quite widely on the east and west coasts of North America, but in all cases the presence of the complete paragnath armature is either expressed or implied.

SYLLIDAE

Autolytus verrilli Marenzeller, *Polybostrichus* phase

Wesenberg-Lund, 1947, p. 33.

A polybostrichus stolon about 7 mm. long and 1.5 mm. wide corresponds closely to Wesenberg-Lund's description of that of this species. It is readily distinguished from the corresponding forms of the two small species of *Autolytus* (*A. prismaticus* (Fabricius) and *A. trilineatus* Berkeley) previously described

from the Canadian Pacific area by the presence of 14 unmodified anterior segments, and from that of *A. magnus* Berkeley by the relatively slender base of the palps. The other large *Autolytus* of the region (*A. varius* Treadwell) is known only in the sacconereis phase. Judging from that phase the anterior region of the polybostrichus would probably consist of 14 setigers and it is possible that the present specimen is a small example of it.

A. verrilli Marenzeller is recorded by Chamberlin (1920, p. 12*b*) from Bering Sea under the name *A. alexandri* Malmgren, but hitherto it has not been taken south of this on the west coast of North America.

Collected by Mr. G. H. Wailes in 1928 in the Gulf of Georgia in plankton, together with a number of specimens of *A. magnus* Berkeley.

Exogone hebes (Webster and Benedict)

Webster and Benedict, 1884, p. 716 (as *Paedophylax*); Fauvel, 1923, p. 308.

Five specimens from Sandy Cove, Digby, N.S. The species is recorded both from Provincetown, Mass. (1884), and from Eastport, Maine (1887), by Webster and Benedict. In the latter case it is said to be rare. It has not previously been recorded from Canada. Treadwell (1948) records *E. brevicornis* (Webster and Benedict) from the Bay of Fundy. This species differs from *E. hebes* in having minute and equal antennae (they are well developed and the median one is much the longest in *E. hebes*). The dorsal cirri and the setae also differ widely in the two species.

Phyllodocidae

Eteone arctica var. *robertiana* McIntosh

McIntosh, 1908, p. 103.

A collection of specimens belonging to the genus *Eteone*, from mud-flats at Wedgeport, Yarmouth, N.S., consists of two distinct forms. All are small, the largest about 12 mm. long, the majority much smaller. Little colour remains in the specimens. One of the two forms agrees reasonably well with *E. arctica* Malmgren, a species which has already been recorded from the Bay of Fundy (Treadwell, 1948). The other differs chiefly in having the median dorsal cirri elongate and the anal cirri long, subulate, and colourless rather than almost globular and pigmented as in *E. arctica*. These and other characters agree with the variety of *E. arctica* described by McIntosh (1908) under the name *robertiana*. The variety is new to Canada.

Eunicidae

Lumbrinereis bifilaris Ehlers

Hartmann, 1944a, p. 153.

This is a western American species which has not been recorded previously north of California. *L. bifurcata* McIntosh is not uncommon in British Columbia waters and differs from the present species mainly in having black, instead of yellow, acicula.

Dredged in 60 fathoms off Snake Island, Nanaimo district.

Ninoe nigripes Verrill

Verrill, 1873, p. 595; Hartman, 1942, p. 53.

Several fine specimens from Sandy Cove, Digby, N.S., agree completely with Verrill's and Hartman's descriptions. The largest entire specimen is as preserved at least 45 mm. long; the width of the widest about 3 mm. Branchiae extend to the 33rd setiger, slightly further posteriorly than recorded, probably corresponding with the large size of the specimens. The dark colour of the neuropodia, due to that of the groups of acicula and the bases of the setae, which character doubtless gives the name to the species, is very conspicuous. The crotchets agree closely with Hartman's (1942, Fig. 97) figure. There are already two or three of these in the first setiger. The species is new to Canada.

Glyceridae

Ophioglycera gigantea Verrill

Verrill, 1885, p. 436; Hartman, 1950, p. 37.
Goniada eximia Ehlers, 1901, p. 157. **New Synonymy.**

The genus *Ophioglycera* was set up by Verrill (1885) for examples of the present species collected at Newport, R.I. Verrill's description has since been emended by Hartman (1950) on the basis of an incomplete specimen, believed to have also been collected by Verrill in the same locality, which is now in the Peabody Museum of Natural History, Yale University. Excepting these two descriptions the species has not been recorded under its original name. Seven examples, in good condition, from mud-flats at Kingsport, N.S., occur in the present collection. They vary in length from 320 mm. to 100 mm. and in width from 10 mm. to 5 mm. From these examples we have been able to confirm and amplify Hartman's description and, in the light of more complete knowledge of the species, we have no doubt that it is identical with *O. eximia* (Ehlers) which has been described in considerable detail by both Ehlers (1901) and by Monro (1936) under the generic name *Goniada*. It is excluded from this latter genus by the absence of proboscideal chevrons.

The prostomium is conical, divided into nine rings, and has four small, blunt tentacles at its apex. The basal ring is as long as the three most anterior setigers and, in some of the specimens a pair of lateral small eyes can be made out on it. In the anterior region of the body the parapodia are uniramous (Hartman, 1950, Pl. 5, Fig. 2). This region consists of from 56 to 60 segments. In the posterior region they are biramous and have the rami widely separated (Ehlers, 1901, Pl. 20, Fig. 12). The latter region varies considerably in length and in number of segments, which is very large. The form of the parapodium changes very gradually between these two regions, but there is no constancy in the number of transitional segments. An early stage in the transition is shown by Hartman (1950, Pl. 5, Fig. 3).

Between the 80th and 100th setiger both the lobes and the base of the parapodium are considerably elongated giving the general appearance of a marked increase in body-width. However, this increase is only apparent, the

actual body-width does not increase at this point. It remains practically constant for some distance after the apparent increase takes place and decreases very gradually towards the anal end.

The proboscis is as described and figured for *O. eximia* by Ehlers. It terminates in 18 large, soft papillae. The macrognaths have each five teeth and there are about 32 micrognaths in all. The surface of the proboscis is covered with small, blunt, scale-like papillae. There are no chevrons. The setae are as described and figured by Ehlers.

Glycera robusta Ehlers

Ehlers, 1868, p. 656.

This is a common west coast species, but has not been recorded previously from the east coast of North America. A fine specimen was taken by Mr. J. S. McPhail in 1952 at Lunenburg, N.S., and another by Mr. W. L. Klawe from Sandy Cove, Digby, N.S., in 1953.

Spionidae

Spio **butleri** sp. n.

We have five examples of this species, all taken in May, 1953, swimming in tide-pools on a sandy beach at McIntyre Bay, Queen Charlotte Islands. The specimens are frail and their condition of preservation makes examination difficult. The length of the only two entirely complete individuals is about 25 mm. and the width about 1 mm.; there are about 60 segments. The prostomium is long, rounded anteriorly without indentation and produced to an acute point

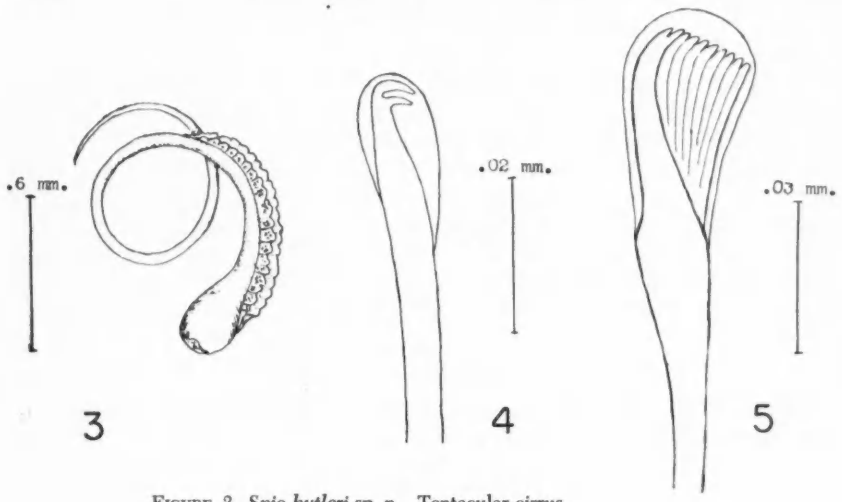

Figure 3. *Spio butleri* sp. n. Tentacular cirrus.
Figure 4. *Spio butleri* sp. n. Crotchet.
Figure 5. *Pygospio elegans* Claparède. Crotchet from 9th setiger.

posteriorly. There are two pairs of small eyes, the posterior pair closer together than the anterior. The tentacular cirri are very long, have a conspicuous thickened base, and carry two well developed, parallel, darkly pigmented, frilled membranes (Figure 3). Branchiae start on the first setiger. The parapodial lobes are not well defined. The branchiae continue to the end of the body where they are very small. The pygidium is inconspicuous and terminates in four indistinct lobes. The notosetae are all capillaries throughout the body. The neurosetae are also exclusively capillary until the 23rd or 24th setiger where they are first accompanied by hooded crotchets. Curved acicular setae are also present in the lower part of the ventral ramus of the posterior parapodia. The majority of the crotchets have two long, parallel teeth set almost at a right angle to the shaft (Figure 4).

The specimens are accompanied by several transparent tubes containing eggs. These tubes are described by the collector (Mr. T. H. Butler, after whom we take pleasure in naming the species) as having been conspicuously red in life and attached to the specimens, but the eggs retain no colour in preservative.

This species differs notably from S. *filicornis* (O. F. Müller), the only other *Spio* recorded from the Canadian Pacific region, in the greater body-length in relation to the width and in the shape of the prostomium and the tentacular cirri. The incidence and the form of the crotchets in the two species also differ considerably. S. *mimus* Chamberlin, recorded from the Canadian Arctic (Chamberlin, 1920) is almost certainly a synonym of S. *filicornis* (see Hartman, 1938). From S. *borealis* Okuda, from Japan, the present species differs most outstandingly in the character of the crotchets. The tentacular cirri of S. *borealis* are, unfortunately, not described.

Pygospio elegans Claparède

Fauvel, 1927, p. 46; Söderström, 1920, p. 267.
Spio rathbuni Webster and Benedict, 1884, p. 726.

This species is represented by a number of specimens from Wedgeport, Yarmouth, N.S., and Sandy Cove, Digby, N.S. It has not been recorded from Canada, but there is little doubt it is synonymous with *Spio rathbuni* Webster and Benedict which is recorded by the describers from Provincetown and Wellfleet, Mass. One of the specimens from Sandy Cove exhibits the very remarkable complex crotchets recorded in the species by Söderström (1920, Figs. 71 and 72). So far as we are aware there is no account showing that these crotchets have been observed since, and their type does not occur elsewhere amongst Polychaeta. The form is shown in Figure 5. They occur in the eighth and ninth setigers.

Genus **Neopygospio**, gen. nov.

As *Pygospio* Claparède, except in that the pygidium terminates in a plate instead of in four heavy cirri.

Neopygospio **laminifera**, sp. n.

Four specimens collected from sand at low tide at Rathtrevor Beach, Nanaimo district, in July, 1951, in small sandy tubes. The two largest are about

15 mm. long and almost 1 mm. wide, another, incomplete posteriorly, is a little wider. There are 45 to 47 setigers. The prostomium is bifurcate anteriorly and is produced posteriorly nearly to the third setiger, terminating in a sharp point. The four eyes are regularly placed. There are 12 to 15 pairs of branchiae, beginning on the seventh setiger. Bladed capillaries occur in both rami in the first six or seven setigers and in the notopodium thereafter. Hooded, bifurcate neuropodial crotchets start at the eighth setiger (Figure 6). The pygidium terminates in a rounded plate deeply incised on the dorsal side (Figure 7). Eggs are present in one specimen and probably all are female. No coloration remains except a few intersegmental dark spots dorsally in the anterior region.

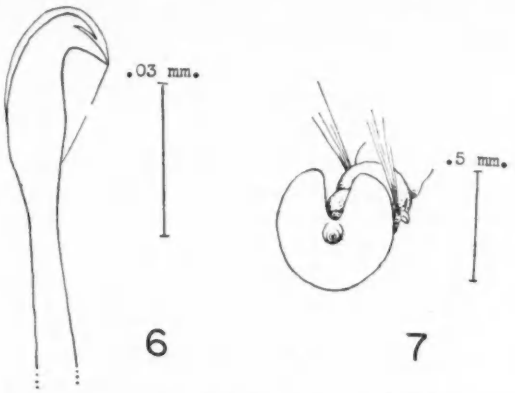

FIGURE 6. *Neopygospio laminifera* sp. n. Crotchet.
FIGURE 7. *Neopygospio laminifera* sp. n. Pygidium.

With the exception of the entirely different pygidium this species is very similar to *Pygospio elegans* Claparède, the type-species of its genus, the other main differences being in the number of pairs of branchiae and their incidence. It diverges further in these respects from *Pygospio californica* Hartman (Hartman, 1936, p. 50) as well as in the shape of the prostomium.

We have made the present species the type of a new genus, rather than modify the original definition of *Pygospio* to contain it, because the essential difference, that of the form of the pygidium, is made the outstanding characteristic in that definition (see Claparède, 1863, p. 37).

Spiophanes bombyx (Claparède)

Fauvel, 1927, p. 41.

This species is known from the west coast of Canada but has not previously been recorded from the east coast. It is very close to, if not identical with, *Spiophanes verrilli* Webster and Benedict described from Wellfleet, Mass. (Webster and Benedict, 1884, p. 728). Hartman (1945, p. 31) regards the two species as identical; Söderström (1920, p. 244) has some doubt as to the identity. The species is represented by a single specimen in two pieces from Wedgeport,

Yarmouth, N.S. It is only 25 mm. long; small, judged by European or western Canadian standards, but within the range given by Hartman (1945) for examples from North Carolina.

Polydora ligni Webster

Webster, 1886, p. 148; Söderström, 1920, p. 265.

This is another species known from the northeastern United States and from western Canada, but not previously from eastern Canada. It is represented by a single specimen from Sandy Cove, Digby, N.S., 3 to 4 mm. in length, but incomplete posteriorly. This is very small compared with specimens from western Canada (E. and C. Berkeley, 1936, p. 47) and from California (Hartman, 1941, p. 309), which may attain 30 to 35 mm. in length. It is in accord with the measurement given by Webster for specimens from New Jersey.

Polydora quadrilobata Jacobi

Fauvel, 1927, p. 54; Söderström, 1920, p. 257.

Excepting a record made by us (1943) from Hudson Bay this north European species has hitherto not been known from North America. A complete specimen and portions of two others were collected intertidally by Mr. W. L. Klawe at St. Andrews, N.B. The complete specimen is very curled and difficult to measure, but seems to be about 30 mm. long. This is rather longer than previous records we have seen. The setae of the fifth setiger are quite characteristic.

Streblospio benedicti Webster

Fauvel, 1927, p. 106 (as *S. shrubsolii*); Webster, 1886, p. 149.

It is doubtful if this species has previously been recorded from Canada. Webster and Benedict in their report on the Annelida Chaetopoda from Eastport, Maine (1887), record it from "Clam Cove", St. Andrews Bay. This may refer to St. Andrews, N.B. The present collection contains several typical specimens from Wedgeport, Yarmouth, N.S., and from Sandy Cove, Digby, N.S.

MALDANIDAE

Euclymene elongata (Webster)

Webster, 1886, p. 154 (as *Praxilla*).

Several specimens, only two of which are entire, from Wedgeport, Yarmouth, N.S., mud-flats. The longer complete specimen measures 140 mm. in length and about 1.5 mm. in width at the widest point, as preserved. This is both longer and narrower than Webster records. There are 39 segments. The general agreement with Webster's description is close. The species was collected by Webster from New Jersey and by Webster and Benedict (1884) from Provincetown and Wellfleet, Mass., but it does not seem to have been noted since. Like these earlier records from further south, the Canadian specimens were found associated with *Axiothella torquata* (Leidy).

CAPITELLIDAE

Heteromastus filiformis (Claparède)

Fauvel, 1927, p. 150.

Now recorded from Wedgeport, Yarmouth, N.S., and Sandy Cove, Digby, N.S., this species has not been recorded previously from Canada. It is known from the eastern United States from New England to southern Florida (Hartman, 1945, p. 37).

Capitella capitata (Fabricius)

Fauvel, 1927, p. 154.

Previously recorded from Canada only from Hudson Bay (E. and C. Berkeley, 1943) this species is represented by three small specimens, 3 to 4 mm. long, from Sandy Cove, Digby, N.S. It is known from Eastport, Maine (Webster and Benedict, 1887) and from Provincetown and Wellfleet, Mass. (Webster and Benedict, 1884).

TEREBELLIDAE

Genus **Novobranchus**, gen. nov.

Cephalic lobe enlarged, bearing a mass of fine tentacular filaments of two kinds. Some branchiae frilled, sessile rosettes or narrowly lanceolate.

Novobranchus **pacificus**, sp. n.

A single specimen taken at Buccaneer Bay, B.C., in 25 fathoms in September, 1918 (collector unknown). The specimen is a complete mature female measuring about 40 mm. in length and 7 mm. in width at the widest point. It is much contracted and poorly preserved.

The cephalic lobe is enlarged and folded and bears a mass of fine tentacular filaments, some of which are long and thread-like with dilated ends, others

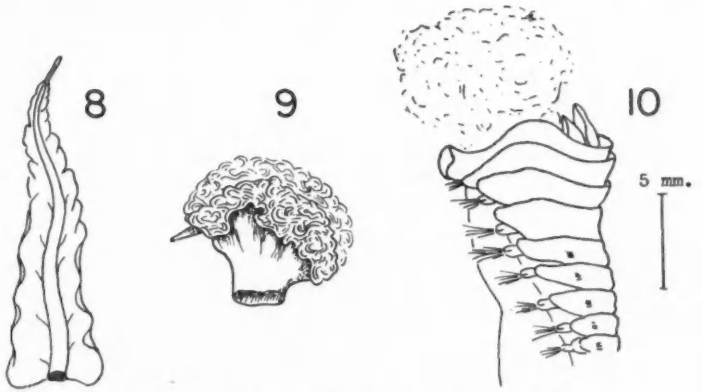

FIGURE 8. *Novobranchus pacificus* sp. n. Branchia from 3rd segment.
FIGURE 9. *Novobranchus pacificus* sp. n. Branchia from 5th segment.
FIGURE 10. *Novobranchus pacificus* sp. n. Anterior region, lateral view; tentacular filaments only indicated.

shorter, heavier, and grooved. There is a pair of branchiae on the third segment, another pair on the fifth, and marks which appear to be scars left by a pair on the second and on the fourth respectively. The branchiae on the third segment are narrowly lanceolate, with a heavy central stem terminating in a filiform tip and with frilled flanges (Figure 8), those on the fifth are much-frilled rosettes (Figure 9). The peristomium has a definite underlip, beneath which is a central projection borne on the second segment. The fourth segment has a wide collar projecting ventrally, laterally and dorsally, the free ends meeting over the dorsum, and the fifth has a similar but smaller collar, to which it is joined by the first notopod. Collars also occur on the sixth and seventh segments, but are successively not as tall as the more anterior ones (Figure 10). There are 16 prominent thoracic notopodia starting on the fifth segment with notosetae of two kinds, long-bladed capillaries alternating with very fine, shorter hair-like ones (Figures 11 and 12). Thoracic uncini start on the fourth setiger (eighth segment) on small, insignificant tori and are all of one kind, crotchets with long, bent shafts terminating in a single large hook surmounted by a bunch of denticles (Figure 13). The abdominal pinnules are prominent and long and carry very small avicular uncini on long supports (Figures 14 and 15).

This species is clearly allied to the members of the subfamily *Trichobranchidea* Malmgren (*Trichobranchinae* Fauvel). It resembles *Octobranchus antarcticus* Monro (Monro, 1936, p. 185) in many respects, differing mainly in the type of branchiae, but the description of that species is based on a very

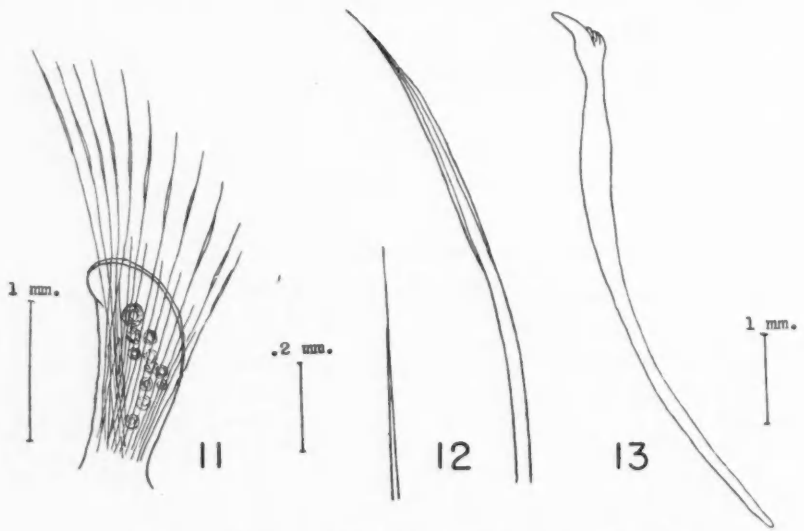

FIGURE 11. *Novobranchus pacificus* sp. n. Thoracic notopodium.
FIGURE 12. *Novobranchus pacificus* sp. n. Thoracic notosetae.
FIGURE 13. *Novobranchus pacificus* sp. n. Thoracic uncinus.

incomplete specimen. In the branchiae and in the presence of two kinds of tentacular filaments it differs from *O. lingulatus* (Grube) (Fauvel, 1927), *O. japonicus* Hessle (1917) and *O. phyllocomus* Hartman (1952) and, in addition, from the first two by having two types of notosetae.

Opheliidae

Ophelia borealis Quatrefages

Tebble, 1952, p. 554.

A single specimen in good condition taken from the stomach of a lemon-sole (*Parophrys vetulus*).

Hitherto this species has been widely regarded as a synonym of *O. limacina* (Rathke) (Fauvel, 1927, p. 132; McIntosh, 1915, p. 10). Tebble (1952, p. 553) has recently advanced reasons for considering that separate identities should be maintained. The chief characters on which he bases differentiation are (1) the number of setigers and the relative numbers of these which are prebranchial, branchial and postbranchial, respectively; (2) the number of dorsal anal papillae and their length relative to that of the ventral ones; (3) the length of the setae of the postbranchial setigers. The present specimen has 36 setigers, of which

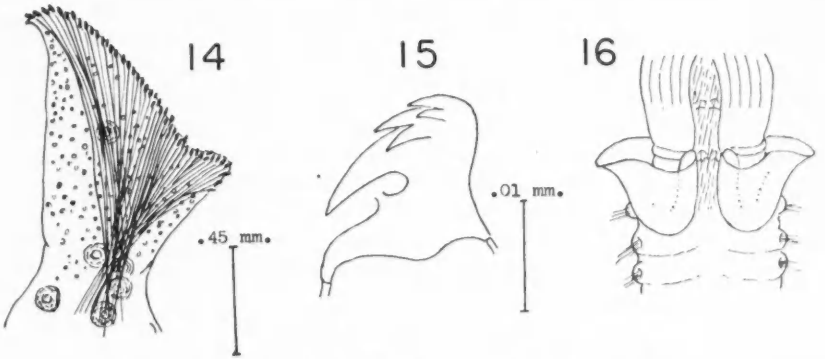

Figure 14. *Novobranchus pacificus* sp. n. Abdominal pinnule.
Figure 15. *Novobranchus pacificus* sp. n. Abdominal uncinus.
Figure 16. *Distylia volutacornis* (Montagu) var. *pacifica* var. n. Collar.

10 are prebranchial, 20 branchial and 6 postbranchial; its dorsal anal papillae are long, almost as long as the ventral ones, and the setae of the postbranchial setigers extend well beyond the anal cirri. It thus represents a typical *O. borealis* Quatrefages as diagnosed by Tebble.

This is the first record of any species of *Ophelia* from the Canadian Pacific region, but *O. limacina* (Rathke) has been recorded from the west coast of North America, both north and south of Canada. We have ourselves listed it from Nunivak Island, Alaska, and from Cleveland Passage, Alaska (1942), and it was found on the Oregon coast by Hartman and Reish (1950). From Northern

California it is listed by Hartman (1938 and 1944b) and from Southern California by Hartman (1938) and by ourselves (1941). Re-examination of our own material in the light of Tebble's classification confirms our identification of the specimens from Cleveland Passage, Alaska, as *O. limacina* (Rathke), but those from Nunivak Island, Alaska, agree more nearly with his interpretation of *O. borealis* Quatrefages. Tebble (*in litt.*) expresses the opinion that our specimens from California belong to neither of these species, but to his recently described species *O. assimilis* (Tebble, 1953, p. 367). We are by no means convinced, however, that specific differentiation in the genus *Ophelia* can be reliably based on such detailed separation of characters as Tebble attempts.

The lemon-sole in the stomach of which this specimen was found was taken in Hecate Strait by Dr. K. S. Ketchen.

Sabellidae

Distylia volutacornis (Montagu), var. **pacifica** var. n.

Fauvel, 1927, p. 307 (stem-species, as *Bispira*).

A single example of this variety measures 30 mm. in length, including the branchial plume (which makes up about a third of the total length), and 2 mm. in width at the widest point. The branchial filaments are spirally coiled, united basally by a palmar membrane extending for about a fifth of their length, and are produced terminally into rather long, fine bare tips. There are four or five pairs of ocular spots on each filament. In all these respects and in that of the setae the variety resembles the stem-species. However, the collar is entirely different. In the stem-species it is four-lobed with the dorsal lobes widely separated. In the variety there are only two lobes which are curled inwards and nearly meet on the dorsal side. They are flared and stand well away from the branchial plume (Figure 16). No conspicuous colour remains in the specimen.

Dredged off Clarke Rock, Gulf of Georgia. (Collector and depth unknown.)

(?) *Euchone rosea* Langerhans

Fauvel, 1927, p. 340.

The stomach-contents of a young lemon-sole (*Parophrys vetulus*) caught in Hecate Strait in 30–50 fathoms by Dr. K. S. Ketchen consisted almost entirely of a representative of the genus *Euchone* not more than 4 mm. long.

The material was partially digested, but the size, the small number of setigers (eight thoracic and eight or nine abdominal), the form of the collar and of both the thoracic hooks and abdominal uncini seem to agree with *E. rosea* Langerhans, a species which has not been recorded hitherto from the Canadian Pacific region.

Fauvel (1927) and McIntosh (1923) think *E. rosea* is, perhaps, the young form of *E. analis* (Kröyer), a species which is known from this region, but Southern's (1914, p. 146) record of "mature" examples of *E. rosea* only a few millimetres long seems to throw doubt on this identity.

Fabricia sabella (Ehrenberg)

Fauvel, 1927, p. 325; E. and C. Berkeley, 1952, p. 121.

This species is represented by specimens from both Wedgeport, Yarmouth, N.S., and Sandy Cove, Digby, N.S. It is known from western Canada and from Hudson Bay (E. and C. Berkeley, 1943), but not from eastern Canada though *Haplobranchus atlanticus*, recorded by Treadwell (1932) from St. Andrews, N.B., seems to be a very nearly allied, if not identical, form.

Myxicola aesthetica (Claparède)

Fauvel, 1927, p. 344.

A large mucilaginous colony of this species recently found between rocks near Dodd's Narrows, Nanaimo, B.C., contains individuals up to 60 mm. long. This seems to be worth noting since we have been unable to find previous records of specimens attaining more than 40 mm.

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Effect of Olfactory Occlusion on Migrating Silver Salmon (*O. kisutch*)[1,2]

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ABSTRACT

Silver salmon were captured in traps in Issaquah Creek and its East Fork. The olfactory pits of approximately one-half of the fish were occluded before all of them were displaced to the Issaquah about one mile below the junction of the two streams. The control salmon, unlike those with occluded olfactory pits, showed an excellent ability to repeat their original choice at the stream juncture. This is interpreted to mean that the operated fish were not able to differentiate between the two streams but were distributing themselves in a random fashion. The results, therefore, are in accord with those which would be expected if the fish were relying on their sense of smell in making this choice.

In order for a salmon to return to its parent tributary, it must react to a stimulus from that stream in a manner different from that produced in a fish destined for a neighbouring stream; therefore, a stimulus which produces the same response in all salmon cannot be the directional factor which causes salmon to ascend only the tributary in which they were reared. On the basis of our experiments (Hasler and Wisby, 1951), we proposed an hypothesis of homing which involves a conditioned olfactory response to properties of the water of the parent stream. The fry could become conditioned to the odours present in their natal stream and retain the ability to respond to its odour-complement until their return from the sea. The requirements of an odour, which is to serve as this "guide-post" for returning salmon, are: (1) it must remain relatively constant over a period of years; (2) it must have significance only for those returning migrants which had been conditioned to it during their fresh-water sojourn. Thus, it cannot be a general attractant or one to which all salmon respond in the same manner. And finally, it must remain detectable even though the stream be changed in chemical and physical characteristics. The problem of migration as it relates to sensory mechanisms was recently reviewed (Hasler, 1953, 1954). The experiment described herein represents an attempt to subject the laboratory findings to a test in the field.

The spawning migration of the anadromous forms of salmon and trout has long excited the curiosity of scientist and layman alike, and their eventual return

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to the parent river is well established. Some of the evidence now available indicates that these fish not only tend to return to the parent river system but to the specific tributary in which they were reared. It was the object of this experiment to investigate the mechanism, or mechanisms, by means of which salmon are able to differentiate between their own, and any other, tributary.

EXPERIMENTAL PLAN

A salmon, in returning to its parent stream, is confronted with a problem of discrimination each time a new tributary joins the stream which it is negotiating. If, in each instance, the salmon ascends the stream leading to its natal tributary it will eventually reach its birthplace. If, on the other hand, a non-parent tributary is entered at any one of these confluences, or if the home of its youth is overshot, it will be forced to retrace its path to the point where the mistake was made and resume its journey. That the latter may sometimes be the case is demonstrated by the work of Ricker and Robertson (1935) on sockeye salmon and Taft and Shapovalov (1938) on steelhead trout.

It follows, then, that if it were possible to discover the sense or senses used by salmon at any one of these simple choice situations, valuable information could be gained concerning the sensory system responsible for the successful completion of the journey. Thus, if it were possible to produce, by removal of one or more sensory systems, a salmon which could not consistently make the correct choice at the confluence of two streams, the actual homing mechanism, so far as selection of tributary is concerned, could be predicted. Any information gained in this manner could, of course, only be applied with confidence to that portion of the migratory journey which is concerned with location of the parent tributary—that is, after the salmon has found, and entered, the main river from the sea.

PROCEDURE

The problem of location of the experiment was presented to Dr. L. R. Donaldson of the University of Washington, who suggested a site near Issaquah, Washington, where two confluent streams each support a natural run of silver (coho) salmon. The State of Washington Department of Fisheries operates a salmon hatchery and fish trap on the larger of these two streams, the Issaquah, at a point about one mile above its junction with the East Fork of Issaquah Creek (Figure 1). Silver salmon are regularly permitted to pass through the trap and subsequently to spawn, after the hatchery has taken its quota of eggs. In November, 1952, a fish trap was constructed in the East Fork branch about one and one-half miles upstream from its juncture with Issaquah Creek. It was thus possible to capture fish in either stream, which, presumably, had entered their natal stream system.

A supply of white and yellow Petersen tags obtained from the Department of Fisheries was used exclusively in marking the experimental animals. A coded system of tagging was developed wherein it was possible to identify the site of

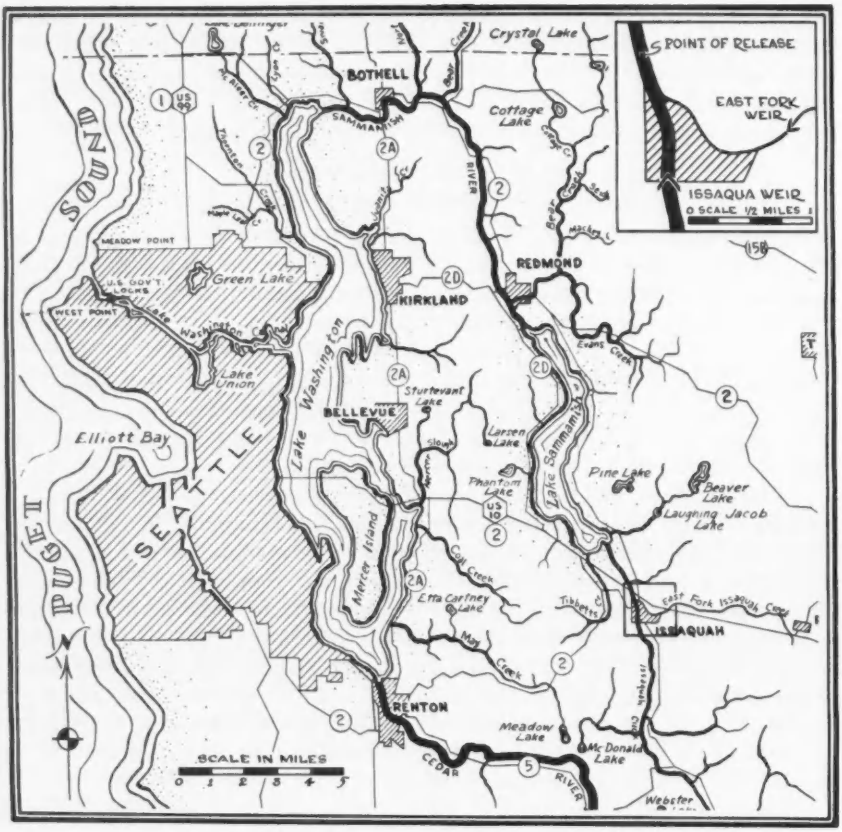

FIGURE 1. Lake Washington watershed, adapted from a map prepared by the State of Washington Department of Fisheries.

marking of those fish which could not be recovered. Thus, a yellow tag on each side, ahead of the dorsal fin, indicated a test fish which had been tagged at the Issaquah wier, while a yellow tag on one side and a white one on the other, in the same position, indicated a control fish from the same source. East Fork salmon were given the same colour combinations but were tagged behind the dorsal fin.

The tagged experimental and control fishes were then displaced to the Issaquah at a point about three-fourths mile below the confluence of the two streams. It was thus possible to determine, by recapturing the fishes at the two traps, whether or not they had duplicated their original path when they again reached the fork.

The original scope of this experiment included the elimination of function of several of the sensory systems including visual, common chemical, and

olfactory. Scarcity of manpower, as well as of migrating salmon, militated against such an ambitious program. The experiment was therefore confined to occlusion of the sense of smell, with which the laboratory investigations had been concerned.

Elimination of olfaction was accomplished by plugging the olfactory pits with vaseline, benzocaine ointment, cotton or a combination of these (Figure 2). In any case, water was prevented from contacting the rosette of olfactory tissue. Admittedly, an olfactory organ is intact until the nerve, or the brain site, is destroyed. Simple occlusion does not render the olfactory capsule incapable of odour detection. However, it seems unlikely that a fish could orient toward an olfactory stimulus when the flow of water over the sensory tissue is stopped.

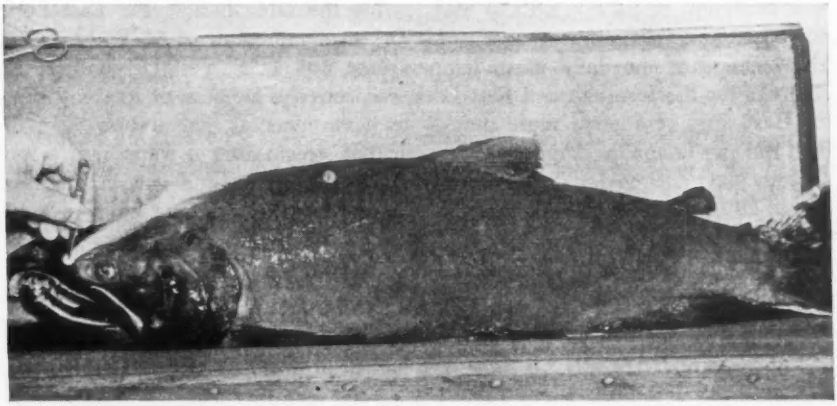

FIGURE 2. Method of inserting a cotton wad into the olfactory pit of a tagged Silver salmon. (Approx. length, 26 in.)

The benzocaine ointment was used primarily because it could be easily introduced while warm, and therefore soft, but would congeal at the prevailing low water temperature and therefore could not be washed out. At the outset, the anaesthetic property seemed desirable, but was later found to be unnecessary. In a few fish, the olfactory nerves were cut by inserting the blade of a knife behind the olfactory pits. An equal number of controls were traumatized by making a similar incision anterior to the olfactory pits. So few fish from these two groups were recaptured that they were omitted in the analysis. It is thought that the severity of the operation prevented them from moving upstream after having been reintroduced.

EDAPHIC CHARACTERISTICS OF THE STREAMS

Issaquah Creek, with its tributaries, empties into Lake Sammamish which is in turn connected with Lake Washington through the Sammamish River. The Lake Washington Canal then establishes contact with the sea. A fish which is

returning to the Issaquah is forced to travel some 40 stream miles, by-passing 15 to 20 tributary streams on the way. Assuming that the fish reaches its objective without having strayed while en route, it will have moved in almost all compass directions, through streams and lakes.

Both the Issaquah and its East Fork flow through the village of Issaquah. Their junction is immediately below the village and their origins are in the hills lying just south of the village.

The volume of water in Issaquah Creek is much greater than that in the East Fork, although both fluctuate considerably during the period when the salmon are spawning. Field estimates of flow indicated eight to ten times as much water in the Issaquah as in the East Fork.

Temperatures from the Issaquah ranged from a maximum of 50°F. (10°C.) to a minimum of 37°F. (2.8°C.) and, during the same period, the East Fork ranged from a maximum of 48°F. (8.9°C.) to a minimum of 36°F. (2.2°C.). The average of the daily mean temperatures was 44°F. (6.7°C.) and 41°F. (5.0°C.) for the Issaquah and East Fork, respectively. Because of its small size, the East Fork responded more quickly to environmental temperature changes than did the Issaquah, being warmer than that stream after a warm rain or on a sunny day, and colder on a cold day. Since the salmon run was in progress during all of these conditions, temperatures of the streams cannot have affected the fishes' choice.

RESULTS

A total of 302 fish were displaced downstream; 149 were controls and 153 had plugged olfactory pits. Of these, 226 had been captured at the Issaquah site and 76 in the East Fork. From Table I it can be seen that all of the control fish from the Issaquah, which were recaptured, had returned to that site on their second attempt, while 71 per cent of the recaptured East Fork controls had returned to the East Fork trap. On the other hand, of the Issaquah-recaptured salmon whose sense of smell was eliminated, 23 per cent entered the East Fork trap on their second attempt and, of those captured at the East Fork trap, only 16 per cent were recaptured at this site (Table II).

In order to assess the effect of the plugging operation, the number of control recaptures was compared with the operated recaptures (Table III). No significant differences were found in this respect. It must therefore be concluded that the

TABLE I. Distribution of recaptured control silver salmon. ($\chi^2 = 0.488$, Probability = 0.49)

	Recapture site	
Capture site	Issaquah	East Fork
Issaquah	100%	....
(46 fish)	(46)	(0)
East Fork	29%	71%
(27 fish)	(8)	(19)

TABLE II. Distribution of recaptured plugged silver salmon. ($\chi^2 = 43.72$, Probability < 0.001).

	Recapture site	
Capture site	Issaquah	East Fork
Issaquah (51 fish)	77% (39)	23% (12)
East Fork (19 fish)	84% (16)	16% (3)

TABLE III. Effect of olfactory occlusion on the recapture of tagged silver salmon. ($\chi^2 = 0.30$, Probability = 0.60).

	Total tagged	Recaptured	Not recaptured
Control	149	73	76
Treated	153	70	83

operation affected only their ability to make the proper choice at the juncture of the two streams and did not, as had been feared, otherwise deter them in their migration. It is not known whether spawning was successful in any of these individuals since, in the large majority of cases, the tags and plugs were removed from the recaptured fish before they were returned for the last time to the stream.

DISCUSSION AND SUMMARY

From inspection of the data it is apparent that the normal fish showed an unusual ability to repeat their original choice at the stream juncture, thus furnishing additional evidence for the home stream theory. The operated ones, however, were unable to do so. Interfering with the orientive aspects of the sense of smell by this method seriously reduced their ability to repeat their original path, and this is interpreted to mean that the operated fish were not able to differentiate between the two streams but were distributing themselves in a random fashion. The results are in accord with those which would be expected if the fish were relying on their sense of smell in making this choice. The possibility exists that these fish, in one ascent during their adult life, learned the route and were thus able to retrace their path after having been displaced downstream. If this were the case, the initial ascent would not have been made as a result of a "homing" drive but rather because of a general tendency to swim upstream. Moreover, previous experiments have indicated that adult fish do not learn as rapidly, nor do they retain their learning as long, as young fish (Hasler and Wisby, 1951). Be that as it may, the orientation in this instance appears to have been accomplished by olfaction. Absolute proof must await additional data from other experiments.

While many researchers have speculated about the mechanism which guides salmon to their natal tributary, only one previous worker has attempted to investigate the sense of smell in this respect. Craigie (1926) tagged and released

500 sockeye salmon in half of which the olfactory nerve had been severed. Variables inherent in the experimental design, however, made interpretation of the results difficult. The salmon had been captured by a fishing vessel in Cold Water Bay and were presumed to be destined for the Fraser River system, 125 miles to the south. There was no way, however, to insure that this actually was the destination of all of the fish; furthermore, the control fish were not traumatized without severing the nerve. That the operation is a severe one is evident from the fact that they tended to "sulk" in the vicinity of the release site and almost as many were recaptured there as in the Fraser River proper. It would be difficult to determine whether the slightly higher incidence of straying in the operated group was owing to lack of a sense of smell or to the distraught wandering of an injured animal.

It is true that the wiers in our experiment were both located so close to the junction of the two streams as to afford little opportunity for a fish to retrace its path in the event of a mistake (Ricker and Robertson, 1935). The experiment was of necessity conducted under the assumption that such an occurrence was equally likely in either stream and would not seriously mask the true ability of the fish to find its home stream, and this proved to be the case.

It is recognized that these data would be more valuable if more fish had been available, also if elimination of other sensory systems had yielded negative results. It is, however, the only evidence of this type to date and is presented in the hope that it will stimulate other scientists to undertake similar studies.

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The Abundance and Distribution of Entomostracan Plankton at Lakelse Lake, B.C., 1949-1952[1]

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ABSTRACT

Greatest concentrations of entomostracans at Lakelse Lake in 1949 were in the upper half of a 30-metre column. The copepods were quite uniform in horizontal distribution over the deeper part of the lake while the cladocerans tended to concentrate at the north end. A high abundance of entomostracans occurred between mid-July and mid-October. Sampling at the deepest station only may be sufficient to give an indication of the total incidence of *Cyclops* sp. in the lake, but a true representation of total abundance of the other entomostracans cannot be obtained by this restricted method of sampling. An apparent decline in the occurrence of entomostracans following 1949 can probably be attributed, in part at least, to a change in efficiency of the collecting nets used.

INTRODUCTION

Lakelse Lake in the lower Skeena River drainage is the site of research on the freshwater life history of sockeye salmon. As the young sockeye spend a full year in the lake the freshwater food supply is important to their growth and survival. This paper records the results of a study of the distribution and abundance of plankton.

Ricker (1937) found that the diet of underyearling sockeye in Cultus Lake consisted chiefly of entomostracan plankters. Analysis of the stomach contents of the sockeye salmon available from Lakelse Lake—those found in the stomachs of predator fish prior to 1949—suggested a similar diet for these salmon in Lakelse Lake. Ricker reported also that certain species of plankters appeared to be "preferred" by the sockeye and that the incidence of different species in the stomachs of the fish differed with the seasons.

One of the objects in the program for Lakelse Lake, commencing in 1949, was to sample the plankton of the lake in such a way that the distribution and relative abundance of the various limnetic entomostracan plankters could be determined. Other limnological and meteorological data were collected to enable correlation of environmental factors with the abundance of sockeye food.

A concentrated effort was put into the sampling of the plankton populations in 1949 in order to obtain a description of the vertical and horizontal distribution of the forms over the entire lake and to determine the feasibility of sampling the plankton populations of the lake at a single station. A diminishing amount of effort was expended in subsequent years, because of the pressure of other work.

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COLLECTION AND ANALYSIS OF PLANKTON DATA

The physical characteristics of Lakelse Lake are recorded by Brett (1950). For the 1949 collections six stations were established on the lake as shown in Figure 1. Station 1 was at the northern extremity at a depth of 5 metres. Stations 2, 3 and 5 were situated in the deeper regions at 15, 30 and 10 metres, respectively. Station 4, at a depth of 5 metres, was located about half a mile west of station 5. The southern shallow portion of the lake was represented by station 6, which was at a depth of 5 metres and about two miles distant from station 5. The stations were chosen roughly on the basis of the lake's volume and area—i.e., the

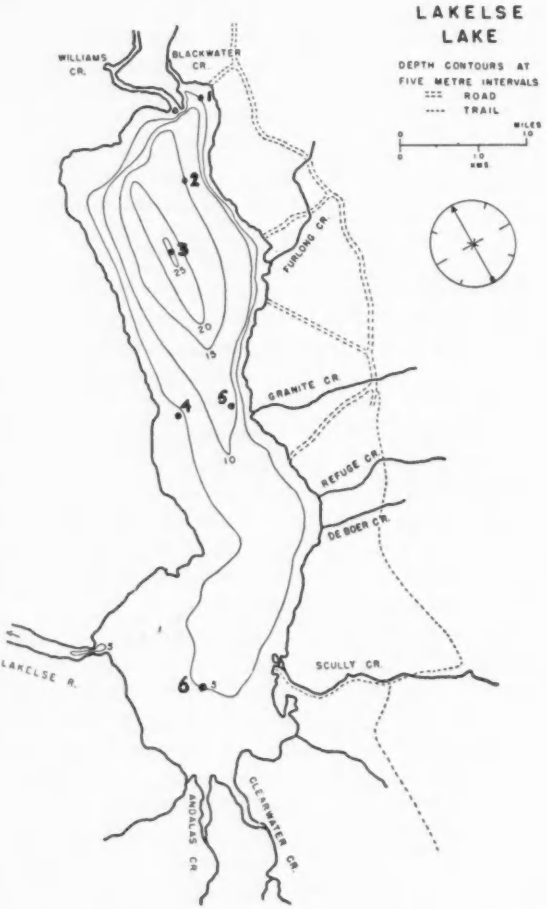

FIGURE 1. Lakelse Lake showing the 5-metre contour lines and the locations of the plankton-collecting stations (1–6).

deeper waters of the northern half were represented by more stations than was the shallow southern half, while no large area of the lake remained unsampled.

The collection method was to draw a Wisconsin-type plankton net through the column of water to be sampled at a rate of approximately 0.5 metres per second. The straining surface of the net and its bucket was made of No. 10 bolting silk. The opening of the net had a diameter of 13 centimetres.

Collections were made weekly throughout the summer and fall of 1949 from each of the six stations. During May and June total vertical hauls were used. From the end of June hauls usually consisted as far as possible of a total vertical haul, and 30- to 15-, 15- to 10-, 10- to 5-, and 5- to 0-metre stage hauls at each station. The plankton net in use for the first part of the season was lost on August 30 and another previously used No. 10 net was put into service. This was replaced by a second "used" No. 10 net on November 7 and all subsequent sampling was done with this net.

Approximately fortnightly samples were collected during the 1950 season, mainly at the deep station 3. In 1951 and 1952 the effort was reduced to approximately monthly collections at the deep station.

In the laboratory the samples were washed from the 4-ounce bottles in which they had been preserved into long narrow test-tubes, and the organisms allowed to settle overnight. A glass siphon, tapered to a fine opening at one end and bent so that the tip would remain at a fixed distance above the bottom of the test-tube, was then filled with water and placed in the tube. The majority of the water and preservative was siphoned from the tube drop by drop in this way. Occasional tests made on the siphoned portion showed that no organisms were removed from the samples by this method. The much reduced contents of the test-tube were then washed into a small graduate. The organisms were once more allowed to settle and the sample was further concentrated by siphoning.

The plankton organisms were removed from the graduate with a pipette and placed in a Sedgewick-Rafter counting cell, which previously had been divided into four longitudinal sections by scoring the underside. With the aid of a binocular microscope and a mechanical tally all entomostracan plankters were counted.

No attempt was made to determine volumes or weights of the samples since the relative numbers of each kind of entomostracan were of prime concern.

LIMITATIONS AND TREATMENT OF THE DATA

Of the three sources of error which Ricker (1938) outlines for plankton research—namely, errors in enumeration, errors in making collections, and errors of representation—only the second need be considered at this time, since the first is concerned with the method of enumeration by fractioning and the last will be discussed in detail later in this paper.

One of the difficulties responsible for errors in collections arises from the fact that a plankton net may not strain all the water in the column through which it is drawn and therefore it may not collect all the organisms that are present in

the column. In order to determine what portion of the plankton present in the column is represented by a net sample, a second collection is made with a trap or pump, or some other device by means of which 100 per cent of the water of the column is strained and presumably 100 per cent of the organisms in the column are captured. By comparing the catches made by the two methods the efficiency of the net can be calculated and a "net factor" obtained, expressed as the reciprocal of the efficiency.

In testing the efficiency of plankton nets made with different mesh sizes of bolting silk, Ricker (1938) found that the efficiency of a net "increases rapidly with increase in size of mesh". The point at which maximum efficiency occurs will presumably also depend upon the size of the organisms being caught. Ricker found that a No. 10 mesh net was far superior to nets of larger and smaller mesh sizes for the collection of entomostracan plankters because (1) this net proved very efficient (mean net factor of 1.151 for three years' use) when compared with pump collections, (2) there appeared to be no change in its efficiency when a series of as many as 20 hauls were taken in quick succession, and (3) "over a period of service of a year and a half no significant change in efficiency occurred, although toward the end of the period the trend appeared to be towards a slight reduction".

LIMNETIC ENTOMOSTRACAN PLANKTERS PRESENT IN THE SAMPLES

The bulk of the limnetic entomostracans of Lakelse Lake comprises two genera of copepods and two of cladocerans. The copepods consist of two species of *Cyclops*—*C. bicuspidatus* (Claus) and *C. serrulatus* (Fisher), and one of *Epischura*—*E. nevadensis* (Lilljeborg). The relative abundances of the two species of *Cyclops* are not known since they were enumerated as a group. The immature stages (nauplii) of the above genera were also present in the samples. *Bosmina longispina* (Leydig) is the most common of the cladocerans; this species and the larger *Diaphanosoma leuchtenbergianum* (Fisher), make up the bulk of these crustaceans. Other limnetic cladocerans found include *Holopedium gibberum* (Zaddach) and *Daphnia longispina* (O. F. Müller). *Daphnia* sp., however, were found in such small numbers that no significance has been attached to their apparent changes in abundance and distribution.

Many of the identifications of the entomostracans were made by Dr. G. C. Carl of the Provincial Museum at Victoria, some by D. F. Alderdice (1946) while studying the plankton of Lakelse Lake, and others by the author.

The primary data on which this report is based have been reproduced for limited distribution (McMahon, 1954); they can be consulted at or obtained on loan from the library of the Pacific Biological Station.

DISTRIBUTION OF PLANKTON, 1949

Vertical Distribution

The numbers of entomostracan plankters counted in each sample were first converted to numbers per cubic metre of water without making any adjustment

for incomplete straining of the water column by the net. Then for the study of the distribution of the forms it was found useful to express the values as percentages of the total of each genus in the column or at all stations. Table I shows the average monthly percentages of occurrence per cubic metre of the plankters in the vertical strata of the deep station 3. In making the conversion of counted numbers first to numbers per cubic metre and then to percentages of the totals, some accuracy in calculation was lost since only first place decimals were considered. The horizontal lines of Table I, therefore, do not necessarily total exactly 100 per cent. The percentages have been plotted graphically in Figure 2. In using percentage values no attention is given to the differences in abundance of the various genera.

The general tendency among all the entomostracans but *Cyclops* appears to be towards greater concentration in the upper half of the 30-metre column of

TABLE I. Vertical distribution of limnetic entomostracan plankters at Lakelse Lake for four months of 1949. The values given for each of the stage hauls represent the numbers of forms per cubic metre expressed as a percentage of the total number of forms in the 30-metre column at station 3.

Month	No. of samples	Stage hauls in metres			
		30–15	15–10	10–5	5–0
		Cyclops			
July	3	37.5	9.2	23.7	29.5
August	5	21.1	14.2	22.1	42.3
September	3	12.1	8.8	20.3	58.6
November	1	9.0	26.9	20.5	43.4
		Epischura			
July	3	2.1	6.3	48.6	42.8
August	5	2.0	6.1	17.2	74.6
September	3	1.8	1.0	2.2	94.8
November	1	0	57.0	35.7	7.2
		Bosmina			
July	3	0	12.3	29.3	58.3
August	5	2.2	15.0	29.2	54.1
September	3	1.2	6.3	15.4	76.9
November	1	10.5	47.7	35.4	6.1
		Diaphanosoma			
July	3	1.5	1.8	25.9	70.7
August	5	0.2	14.5	21.9	63.2
September	3	1.1	0.9	9.1	88.8
November	1	4.3	44.6	44.6	6.4
		Holopedium			
July	3	0	0.3	1.6	98.0
August	5	0	0	0	0
September	3	0	0	0	0
November	1	0	0	0	0

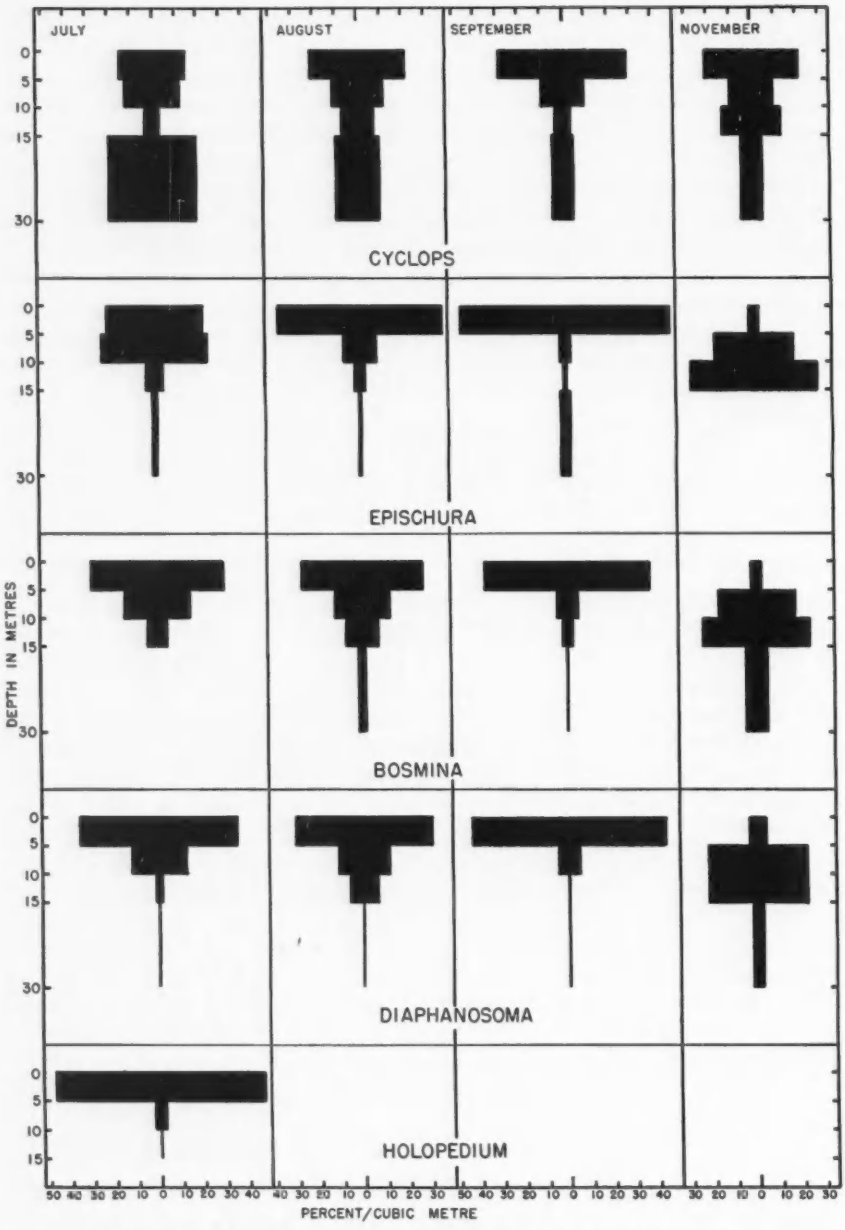

FIGURE 2. Vertical distribution of entomostracan plankters at station 3, Lakelse Lake, 1949.

station 3 during the summer and fall. *Cyclops* was most concentrated in the lower 15 metres during July and became gradually less concentrated in this stratum as the season progressed. By November the greatest abundance of this plankter was in the upper 5 metres. By contrast at no time did the other plankters have more than about 10 per cent of their numbers in the lower half of the column. *Epischura*, *Bosmina* and *Diaphanosoma* were most concentrated near the surface in September and by November had moved downward. *Holopedium* was found during July only at station 3 and at this time was almost wholly in the upper 5 metres of water.

From the data at hand it appears that the vertical distribution is most uniform for *Cyclops* from surface to bottom, and least uniform in the case of *Holopedium*, the other species being intermediate between the two extremes.

Horizontal Distribution

Generally speaking, environmental conditions might be expected to be quite uniform for each stratum of water in a lake of regular shape and depth, and no

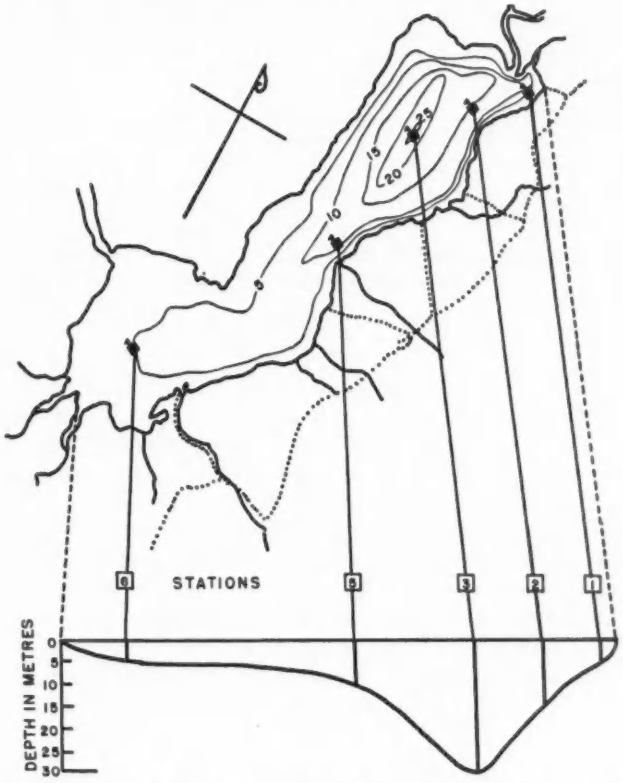

Figure 3. Depth contours of Lakelse Lake in metres and diagrammatic sketch of its basin showing five plankton stations.

great irregularities in the distribution of the plankton would be expected. Thus at Cultus Lake, which is of fairly uniform depth over most of its area, Ricker (1938) was able to show that "the method of choosing a central station to represent the whole pelagic region of Cultus Lake is in general quite satisfactory"—that the plankton was reasonably uniformly distributed over the whole of the offshore region of the lake.

Although the shoreline of Lakelse Lake is quite regular in outline, it is by

TABLE II. Horizontal distribution of limnetic entomostracan plankters at Lakelse Lake for five months of 1949. Values are given in percentages of forms occurring in the upper 5 metres at five stations over the length of the lake.

Month	No. of samples	Stations 1	2	3	5	6
			Cyclops			
May	1	7.2	45.9	21.1	25.4	0.2
June	4	17.9	25.8	28.2	24.9	3.0
July	3	10.9	33.6	19.2	25.2	10.9
August	3	19.3	17.5	26.8	31.8	4.1
September	2	8.6	22.4	22.2	43.5	5.5
Averages		12.8	29.0	23.5	30.1	4.7
			Epischura			
May	1	7.2	53.9	30.9	6.6	1.3
June	4	22.0	21.5	32.2	22.7	1.4
July	3	6.5	27.9	20.8	23.5	21.1
August	3	28.4	14.2	26.2	30.0	1.1
September	2	13.7	19.4	27.3	27.4	12.7
Averages		15.6	27.4	27.5	22.0	7.5
			Bosmina			
May	1	16.6	66.6	0	16.6	0
June	4	44.8	17.8	14.8	18.8	3.9
July	3	19.0	31.3	18.7	23.5	7.3
August	3	22.1	26.0	35.3	9.5	7.1
September	2	22.8	25.2	31.3	17.2	3.3
Averages		25.1	33.4	20.0	17.1	4.3
			Diaphanosoma			
May	1	50.0	50.0	0	0	0
June	4	20.5	27.5	36.2	12.5	3.1
July	3	5.7	54.8	20.5	14.8	3.9
August	3	20.8	22.4	45.4	10.2	1.2
September	2	9.4	27.1	44.3	12.8	6.5
Averages		21.3	36.4	29.3	10.9	2.9
			Holopedium			
May	1	0	0	0	0	0
June	4	53.1	20.7	21.1	5.0	0
July	3	2.2	41.1	32.7	14.5	9.3
August	3	0	0	0	0	0
September	2	0	0	0	0	0
Averages		27.7	30.9	26.9	9.8	4.7

no means uniform in depth. The general shape of its basin is shown diagrammatically in Figure 3. The extensive shelf of the southern half varies from 5 to 7 metres in depth and drops gradually to a depth of 10 metres at approximately the midpoint of the lake. From here the bottom drops off relatively sharply (exaggerated in the diagram) to form a deeper basin in the northern half of the lake, the maximum depth of which is approximately 30 metres.

Since the most northern and southern plankton stations are at depths of 5 metres it was decided that the best way to examine the horizontal distribution of the plankton was to compare the catches from the upper 5-metre stratum over the entire lake. The numbers of each plankter taken at the various stations have been converted to percentages of the total number of that species from all stations. For Table II the individual percentage occurrences have been averaged for each of five months of the spring and summer at each of the five stations down the length of the lake. These have been put into histogram form in Figure 4 which, on the left, shows the monthly averages and, on the right, the seasonal averages for the five stations. The samples taken at station 4 have not been used as they do not contribute information in addition to that provided by the other shallow water stations.

CYCLOPS

Although these plankters were found in greater concentrations at station 2 in May and at station 5 in September than elsewhere, the general tendency, which is most clearly indicated in the seasonal averages, is toward a fairly uniform distribution over the deeper part of the lake (stations 2, 3 and 5). The percentage occurrences at the shallow stations 1 and 6 are relatively low, a situation which might be expected from the fact that these plankters were most abundant in the deeper waters.

EPISCHURA

This large copepod, like *Cyclops*, displays a fairly uniform distribution in the upper waters of the deeper stations and is relatively scarce at the extreme ends of the lake. Although the monthly variation was somewhat greater here than in the case of *Cyclops*, the variation over the season appears to be least for this organism at the deep stations. For some reason a very high proportion of the total occurred at station 2 in May, a situation which was common to most of the forms. Wider fluctuations occurred for this plankter at the northern and southern stations than for other forms, and, as may be seen from Figure 4, relatively high percentage occurrences at station 1 in June and August were accompanied by extremely low proportions at station 6. Conversely, in July a relatively high percentage of this genus appeared at station 6 whereas the proportion was much reduced at station 1 for this month.

BOSMINA

The greatest concentrations of this cladoceran appear at station 2 and there is also a higher percentage occurrence of this form at the most northerly station

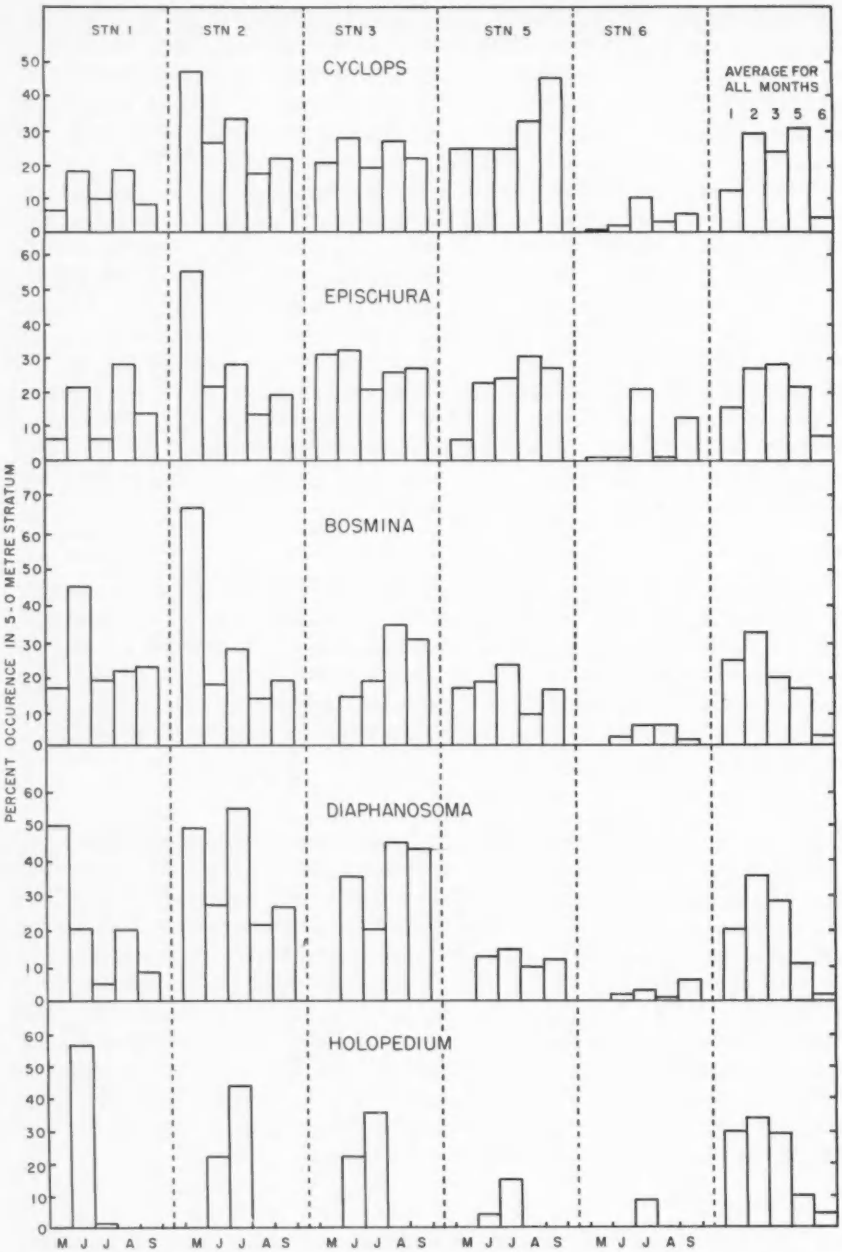

FIGURE 4. Horizontal distribution of entomostracan plankters over the length of Lakelse Lake, 1949.

than for the copepods discussed above. Although there is much fluctuation within the months at most stations, generally this plankter is more concentrated at the northern stations than elsewhere on the lake.

DIAPHANOSOMA

This species displays a horizontal distribution similar to that of *Bosmina*, with the highest proportion of its numbers occurring at the northern stations. The fluctuations in percentage occurrence at these positions are, however, greatest in the case of this cladoceran.

HOLOPEDIUM

The largest of the cladocerans, *Holopedium*, appeared in the collections during only two months of the season – June and July. The majority of these plankters were found at the northernmost station in June while in July the highest percentage of them occurred at station 2.

Wind as a Factor Influencing Horizontal Distribution

The distribution of plankters in a lake is dependent upon factors in the environment and upon the nature of the organisms themselves. Welch (1952) suggests, among other factors, light, food, temperature and the age of the individuals as determinants of distribution. A worthwhile addition to his list, at least as far as horizontal distribution is concerned, must be a number of factors related to meteorological conditions, particularly wind action with the accompanying water movements.

Casual observation at the time of sampling suggested that there were fewer organisms in the samples collected from the southern station on windy days than on calm days. Further examination of the data generally confirmed the observation. Table III shows the numbers of *Bosmina, Diaphanosoma, Cyclops* and *Epischura* per cubic metre at stations 1 and 6 for July and August of 1949 along with the average southerly wind velocities for the period of sampling plus the evening and morning of the day previous to the sampling date. The numbers of plankters and the wind velocities are represented graphically in Figure 5. The numbers of *Holopedium* were too low during this period to warrant consideration here.

It will be seen from Figure 5 that increases in the numbers of *Bosmina* at station 1 are usually accompanied by decreases at station 6. A similar situation occurs with respect to the other entomostracans but with less consistency.

The numbers of the plankters considered, in general, appear to be greatest at station 1 and least at station 6 when there is an increase in the velocity of the southerly wind. Again there seems to be more consistency in the case of *Bosmina*, but the observation is true of the other plankters to varying degrees. The reason for the great surge in the abundance of *Epischura* at station 1 on August 16 remains unknown but it is suggested it may have been the result of local conditions. In general, however, it is evident that the south wind may exert considerable influence in distributing plankton organisms in Lakelse Lake.

TABLE III. Numbers of *Bosmina*, *Diaphanosoma*, *Cyclops* and *Epischura* per cubic metre at stations 1 and 6 for each sampling date of July and August, 1949, and the average southerly wind velocity at the time of sampling and of the evening and morning of the preceding day.

	Station 1				Station 6				Average southerly wind velocity
	Bosmina	*Diaphanosoma*	*Cyclops*	*Epischura*	*Bosmina*	*Diaphanosoma*	*Cyclops*	*Epischura*	
July 5	75	0	346	241	75	15	1,536	904	0.3
12	376	60	1,566	617	60	30	949	1,596	0.3
19	301	30	828	738	75	30	407	2,440	0.0
26	1,280	211	5,482	6,069	30	0	1,024	467	2.0
Aug. 2	166	45	1,777	813	196	30	617	648	0.6
9	1,220	105	4,654	4,247	75	0	151	286	1.6
16	75	166	2,033	11,867	437	30	422	346	0.3
23	1,280	75	617	4,202	226	0	843	120	1.3

For reasons that are not established for Lakelse Lake, many organisms are more abundant in deeper waters than they are in shallow areas. Ruttner (1953) found *Daphnia, Bosmina* and *Diaptomus* to be completely absent from the margin of the littoral shelf at a depth of about 1.5 metres. He reports that *Daphnia* began to occur first at a depth of 7 metres and attained its full population density where the water was about 20 metres deep.

If the southern station at Lakelse Lake is considered to be littoral, then the northern station at the same depth should be similar. However, the sizes of the

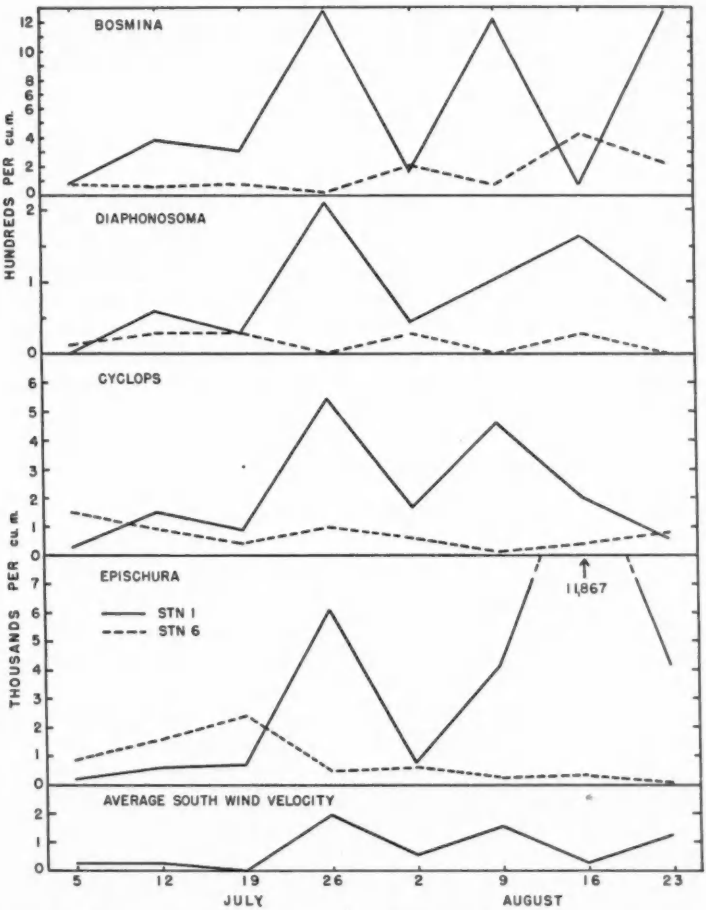

FIGURE 5. Abundance of four genera of plankters at stations 1 and 6 during July and August, 1949, and average of the south wind velocities at time of sampling and in the evening and morning of the preceding day. Wind velocities are measured according to the Beaufort scale.

plankton populations at the two ends of the lake are quite different, the amounts at station 1 being almost invariably greater than those at station 6. Furthermore, in the case of the cladocerans at least, the deepest region of the lake does not appear to be richest in plankton in all cases.

That the entomostracan plankters are not uniformly distributed over the length of Lakelse Lake may be seen from an application of the chi-square test to the data. Using the July 12 samples (chosen randomly) the actual counts for the 5- to 0-metre layer and the chi-squares are as follows:

5–0 m. layer	*Cyclops*	*Epischura*	*Bosmina*	*Diaphanosoma*	*Holopedium*
Station 1	104	41	25	4	0
2	90	103	30	14	238
3	171	155	27	8	126
5	83	156	7	3	7
6	63	106	4	2	36
Mean	102.2	112.2	18.6	6.2	81.4
χ^2	66.4	66.3	31.6	15.6	496.7

From the table of chi-square values (Fisher, 1950) it appears that in none of the above cases is there one chance in 100 of this distribution occurring by chance alone. The heterogeneity demonstrated could involve variations within a small area as well as between remote parts of the lake. There is some suggestion that entomostracans are more numerous over deep water than in shallow. This would contribute to the heterogeneity.

VARIATIONS IN SEASONAL ABUNDANCE, 1949

The numbers per cubic metre of the five genera of entomostracans averaged for the five stations in 1949 appear in Table IV and are represented graphically in Figure 6. The numbers are based on total vertical hauls.

Cyclops is the dominant genus, occurring in relatively large numbers at all times during the spring, summer and fall seasons. The largest numbers are found in the late summer and fall and its numbers do not commence to drop off until mid-October.

The next most abundant form, *Epischura* reaches a peak towards the end of the summer, whereas in the spring and fall its numbers are quite low.

While the occurrence of *Bosmina* in the spring samples was quite infrequent in 1949, the abundance of this cladoceran increased as the summer progressed, coming to a peak about the middle of September. Following this date its numbers dropped off quite rapidly.

A somewhat similar situation occurred in the case of *Diaphanosoma*, the main difference being that the latter form never attained the abundance of *Bosmina*, and reached its maximum numbers slightly later in the season than did *Bosmina*.

The peak in the abundance of *Holopedium* occurred during the third week

TABLE IV. Seasonal variation in abundance of five genera of limnetic entomostracans at Lakelse Lake for six months of 1949. Values are given in average numbers per cubic metre at stations 1, 2, 3, 5 and 6, and are based on total vertical hauls.

Date	*Cyclops*	*Epischura*	*Diaphanosoma*	*Bosmina*	*Holopedium*
May 31	2,201	167	7	9	3
June 7	2,382	438	36	73	129
14	1,763	165	17	27	54
21	2,237	650	120	108	969
28	2,115	179	88	68	94
July 5	1,464	520	57	83	194
12	1,459	1,170	46	159	345
19	1,542	1,981	50	206	33
26	2,736	3,068	146	484	3
Aug. 2	2,708	2,299	76	441	0
9	2,366	2,417	62	581	0
16	1,786	3,539	105	457	0
23	2,744	2,699	54	647	0
Sept. 6	2,709	2,104	150	906	0
13	3,482	2,723	231	969	0
27	3,779	1,029	295	594	0
Oct. 4	3,702	990	185	450	0
18	3,222	434	65	333	0

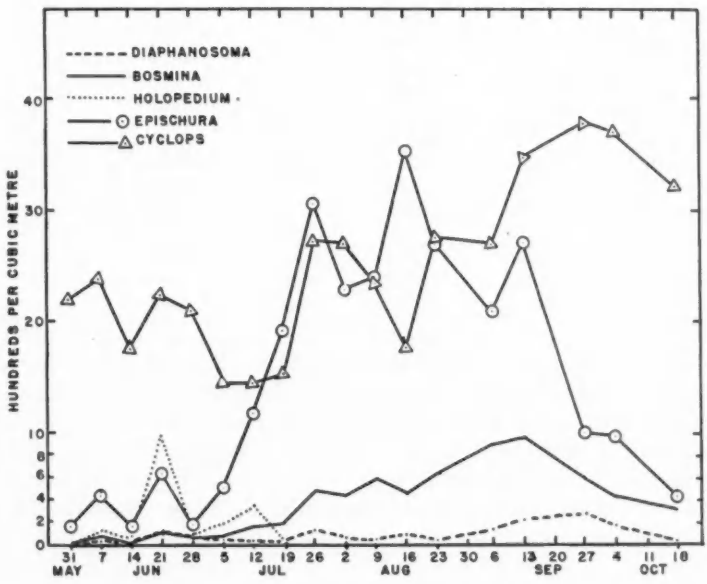

FIGURE 6. Seasonal variation in abundance of five entomostracan plankters at Lakelse Lake, 1949, averaged for five stations. Values are based on total vertical hauls.

of June. Since extremely few individuals appeared in the May sampling and none following July 26, this plankter did not contribute much to the total plankton production of the lake.

Considering the five entomostracans together, the greatest abundance takes place between the middle of July and the middle of October. During the spring and early summer the plankton populations are relatively low and by mid-October they are on a decline after the late summer peak.

In order to demonstrate how representative of the whole lake is sampling at one station throughout the seasons, Table V (numbers of the plankters per cubic metre at station 3 alone) and Table VI (average numbers per cubic metre at stations 2, 3, and 5) have been drawn up. The values from these tables along with those from Table IV, representing average abundance for all stations, are shown graphically in Figure 7.

TABLE V. Seasonal variation in abundance of 5 genera of limnetic entomostracans at Lakelse Lake for 6 months of 1949. Values are given in numbers per cubic metre at station 3. Total vertical hauls are used.

Date	*Cyclops*	*Epischura*	*Diaphanosoma*	*Bosmina*	*Holopedium*
May 31	2,038	163	0	12	0
June 7	5,476	467	35	35	8
14	1,990	278	17	25	15
21	3,885	377	48	50	35
28	4,772	296	113	70	161
July 5	1,719	281	30	43	53
12	2,246	896	30	68	178
19	2,756	861	43	105	75
26	2,199	1,421	63	128	3
Aug. 2	3,040	2,472	58	351	0
9	3,070	1,300	43	316	0
16	1,268	1,057	40	346	0
23	2,043	1,285	23	492	0
Sept. 6	2,329	1,029	133	645	0
13	3,978	838	88	426	0
27	2,892	364	156	344	0
Oct. 4	5,123	2,251	389	499	0
18	2,457	324	113	484	0

It will be seen from the upper portion of Figure 7 that for *Cyclops* the three lines cross one another quite frequently, and that with the exception of a few samples at station 3 only (notably June 7, 21 and 28 and October 4) the station 3 sampling is fairly closely associated with the average for all stations. The deviations from the line representing all stations are reduced in some cases when the averages for the three deeper stations are considered. At other times the deviations of the latter averages are equal to or greater than those for this plankter at station 3 only.

Epischura presents a different situation. Whereas the two lines representing averages for all stations and averages for the three deeper stations appear to be fairly closely associated, the numbers obtained at station 3 alone are almost

always lower. This suggests that there is less likelihood of the deep station being representative of this organism in the lake as a whole that was the case for *Cyclops*. For *Epischura* it appears that station 3 not only is not representative of all stations but it does not seem to represent fairly the deeper stations. On the other hand the averages for the three deeper stations are quite similar to those for the whole lake.

Much the same relationships prevail for *Bosmina* and *Diaphanosoma* as for *Epischura*. Thus the averaged numbers of these organisms per unit volume at stations 2, 3 and 5 present a better representation of the whole lake than do numbers per cubic metre at station 3 only.

In the case of *Holopedium* the small and large averages for the whole lake on June 7 and 21, respectively, do not show up at all in the averages for the deeper stations nor in the station 3 samples. This situation resulted from high

TABLE VI. Seasonal variation in abundance of five genera of limnetic entomostracans at Lakelse Lake for six months of 1949. Values are given in average numbers per cubic metre at stations 2, 3 and 5. Total vertical hauls were used.

Date	*Cyclops*	*Epischura*	*Diaphanosoma*	*Bosmina*	*Holopedium*
May 31	3,251	213	2	10	0
June 7	2,911	484	55	27	9
14	2,165	226	41	30	45
21	3,101	370	44	45	28
28	3,449	233	141	93	157
July 5	1,812	485	89	88	258
12	1,590	1,213	46	120	395
19	2,158	2,243	64	218	25
26	2,392	2,935	173	370	4
Aug. 2	3,716	3,344	101	614	0
9	2,341	2,517	68	537	0
16	2,159	1,827	110	591	0
23	4,087	3,057	65	576	0
Sept. 6	3,101	2,589	159	1,079	0
13	4,527	1,048	219	410	0
27	4,330	961	315	719	0
Oct. 4	5,467	1,163	213	504	0
18	3,378	453	58	365	0

concentrations of this plankter at the northernmost station on those dates, as was discussed under horizontal distribution. Furthermore the peak for the whole lake on July 12 was very poorly represented in the station 3 samples, while the average numbers at stations 2, 3 and 5 very closely approximated those from all stations.

Although sampling at the deepest station appears to represent fairly well the numbers of *Cyclops* in the whole lake, other entomostracans are relatively poorly represented by this restricted method of sampling. Sampling at station 3 only does not give very good indications of the abundance of these forms within that part of the lake over 10 metres deep. On the other hand the average abundance of the three deeper stations closely approximates the average abundance at all

stations for all entomostracan species. It is therefore suggested that at Lakelse Lake, more than one station in the deeper part of the lake should be sampled in order to obtain an indication of the general abundance of entomostracans in the whole lake.

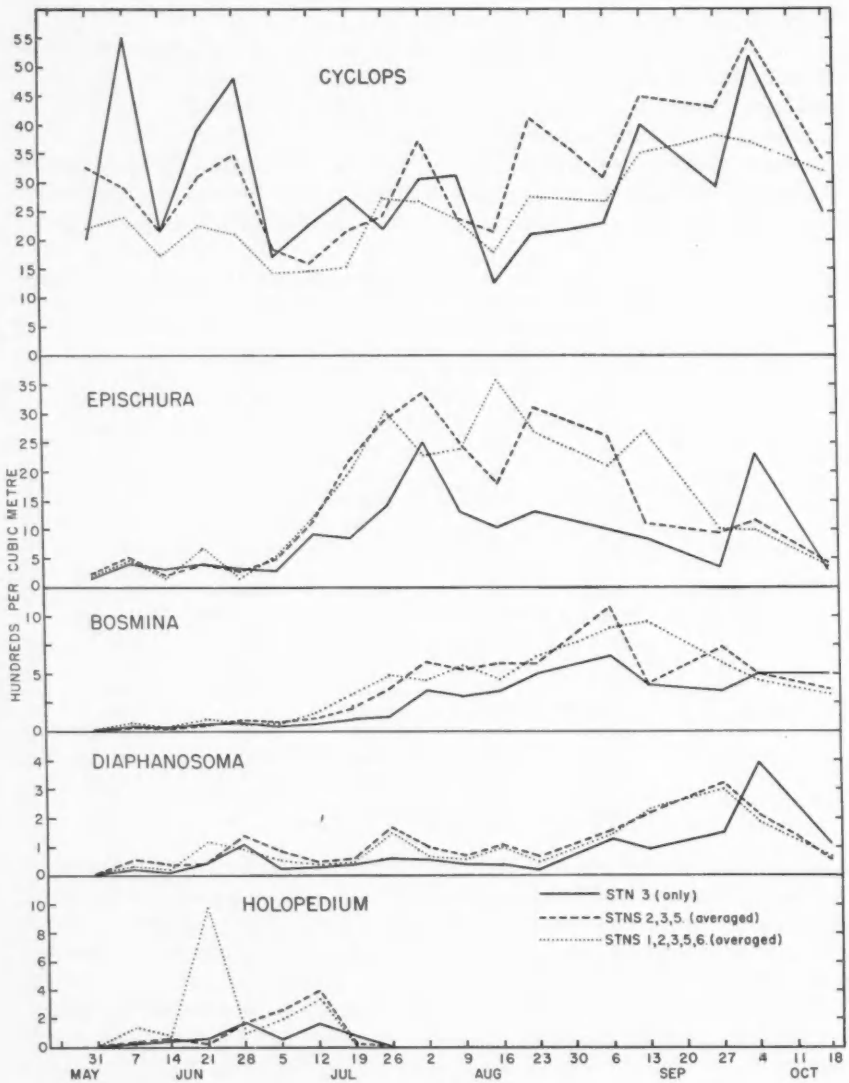
CYCLOPS
EPISCHURA
BOSMINA
DIAPHANOSOMA
HOLOPEDIUM
HUNDREDS PER CUBIC METRE
STN 3 (only)
STNS 2,3,5. (averaged)
STNS 1,2,3,5,6. (averaged)
31 7 14 21 28 5 12 19 26 2 9 16 23 30 6 13 20 27 4 11 18
MAY JUN JUL AUG SEP OCT

FIGURE 7. Seasonal variation in abundance of five entomostracan plankters at Lakelse Lake, 1949. ——— station 3 only; – – – – – stations 2, 3 and 5 (averaged); . . . . . stations 1, 2, 3, 5 and 6 (averaged).

VARIATIONS IN ANNUAL ABUNDANCE, 1949–52

The average numbers per cubic metre of each entomostracan plankter taken in total vertical hauls at station 3 for the four years of sampling are given in Table VII, and Figure 8 is the graphic representation of these.

With the exception of *Diaphanosoma*, entomostracans were considerably more numerous in the 1949 samples than in those of subsequent years. It is not possible to ascribe the difference to biological changes since difference in efficiency of the plankton nets used may have been responsible for this change.

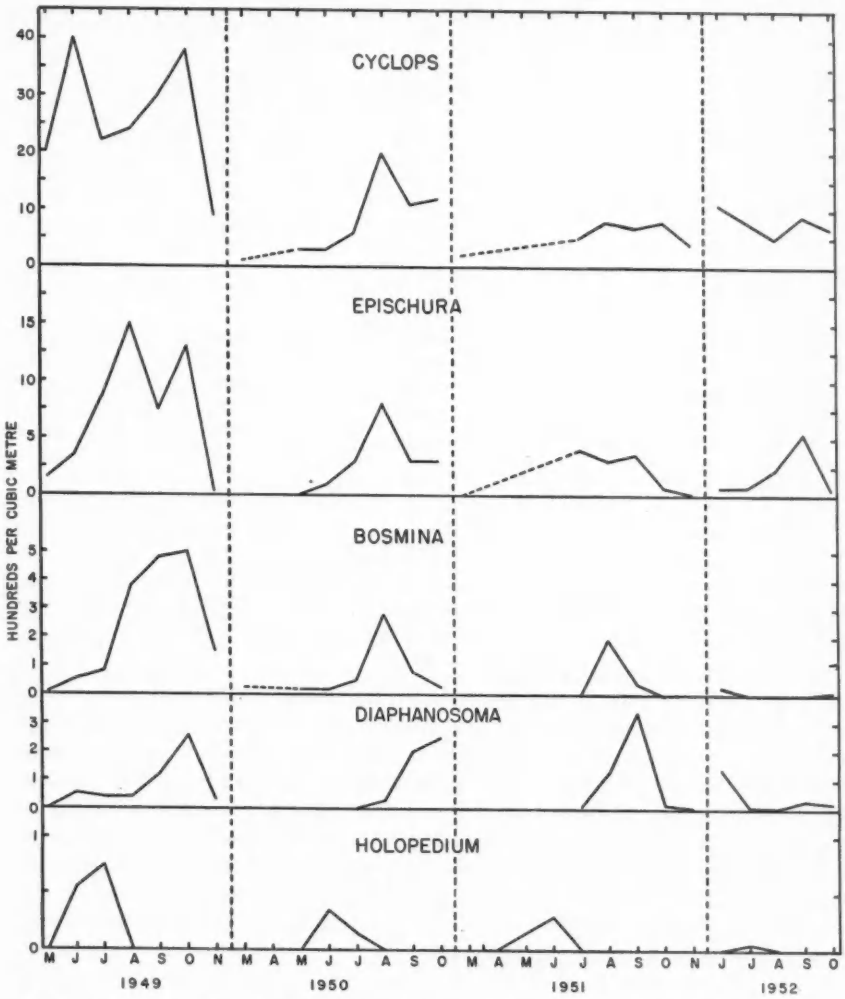

FIGURE 8. Annual variation in abundance of five entomostracan plankters at Lakelse Lake, 1949–52. Based on station 3 total vertical hauls.

TABLE VII. Annual variation in abundance of five genera of limnetic entomostracans at Lakelse Lake from 1949 to 1952. Values are given in monthly average numbers per cubic metre at station 3. Total vertical hauls were used.

Year	Month	No. of samples	*Cyclops*	*Epischura*	*Diaphanosoma*	*Bosmina*	*Holopedium*
1949	May	1	2,038	163	0	12	0
	June	4	4,031	355	53	45	55
	July	4	2,230	865	42	86	77
	Aug.	4	2,373	1,529	41	376	0
	Sept.	3	3,033	744	126	472	0
	Oct.	2	3,790	1,288	251	492	0
	Nov.	1	894	28	33	153	0
1950	March	2	118	0	0	29	2
	May	1	271	0	0	18	0
	June	2	269	96	0	23	34
	July	2	584	315	0	48	13
	Aug.	2	1,965	806	34	276	0
	Sept.	2	1,141	290	231	78	0
	Oct.	1	1,150	296	254	30	0
1951	May	1	208	13	0	0	13
	July	2	545	428	9	3	28
	Aug.	1	771	279	133	186	0
	Sept.	1	665	336	336	38	0
	Oct.	1	788	73	13	0	0
	Nov.	1	361	13	0	3	0
1952	June	1	1,079	70	136	30	0
	July	2	819	69	12	1	4
	Aug.	1	494	223	8	3	0
	Sept.	1	891	552	28	3	0
	Oct.	1	738	58	20	10	0

SUMMARY

The plankton of Lakelse Lake was sampled extensively during the spring, summer and fall of 1949 and to a lesser extent in the three years following. The collections were made with the use of a Wisconsin-type plankton net with a straining surface of No. 10 bolting silk.

From the analyses of the samples, the distribution and abundance of the entomostracan plankton in the lake and the accuracy of representation that might be expected from sampling at one station only, were indicated. In the vertical column at the deepest station it was found, in 1949, that the entomostracans were for the most part concentrated in the upper waters. Horizontally, the two copepods, *Cyclops* and *Epischura* were found to be relatively uniformly distributed in the upper 5 metres over the deeper part of the lake with only small portions of their numbers at either end. The greatest concentrations of the cladocerans, *Bosmina*, *Diaphanosoma*, and *Holopedium*, on the other hand, were found towards the northern end of the lake.

For July and August, 1949, it was shown that in general the heaviest concentrations of entomostracans occurred at station 1 to the north and the least at station 6 to the south when the wind was blowing from the south.

Seasonally the abundance of entomostracans was low in the spring and early summer, increased to a relatively high plateau of production between mid-July and mid-October and then declined.

Except in the case of *Cyclops*, sampling at the deepest station only did not give a true representation of the total plankton abundance for the lake. When sampling was carried out at more than one position in the deeper parts the representation was greatly improved.

Most entomostracans showed an apparent decline in abundance in the years following 1949. It is felt that this may have been partly owing to a change in efficiency in the collecting nets used, but the degree is unknown.

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